This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

3 3433 06908761 1

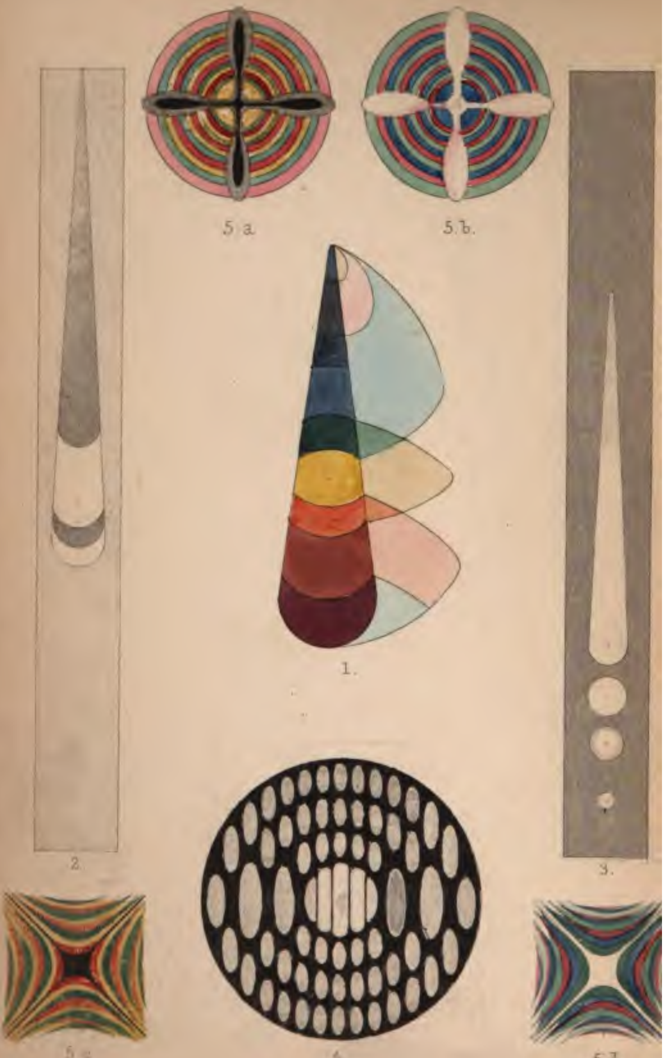
Hunt
3PAF

Hunt
3 [illegible]

THE NEW YORK
PUBLIC LIBRARY

ASTOR, LENOX
TILDEN FOUNDATIONS

PHENOMENA OF THE SUN-BEAM.



1. Light. The Luminous Spectrum. 2. Actinism. The Chemical Spectrum.
3. Heat. The Calorific Spectrum.
4. Diffraction of Light. 5. Polarization of Light.

NEW YORK
PUBLIC
LIBRARY

ELEMENTARY PHYSICS,

AN

INTRODUCTION TO THE STUDY

OF

NATURAL PHILOSOPHY.

[*With* 217 *Wood-engravings.*]

BY

ROBERT HUNT,

PROFESSOR OF MECHANICAL SCIENCE, GOVERNMENT SCHOOL OF MINES,
AUTHOR OF 'POETRY OF SCIENCE,' 'RESEARCHES ON LIGHT,'
'HANDBOOK TO THE GREAT EXHIBITION,' ETC.

LONDON:
REEVE AND BENHAM,
HENRIETTA STREET, COVENT GARDEN.

1851.

PREFACE.

INTIMATE association with those institutions which are devoted to the diffusion of useful knowledge, has led to a conviction that, notwithstanding the increasing desire manifested amongst their members to cultivate an acquaintance with physical science, the means has not been afforded by which this important study might be facilitated.

Impressed with the idea that it is quite possible to render every truth intelligible by the most simple language—that it is practicable to teach physical science so far as to render all the great deductions from observation and experiment satisfactorily clear, without encountering the difficulty of mathematics,—this Elementary Treatise has been written. It is hoped that it may be found useful in furnishing an appropriate introduction to those works of our great natural philosophers, to which we are indebted for a knowledge of the laws which regulate the great phenomena of nature.

Convinced that for a numerous class most of the works on natural philosophy are of too abstruse and technical a character, demanding an amount of previous education which few of our schools have hitherto afforded, this Elementary Treatise has been attempted. The design is, to give accurate information on every important fact connected with Physics; to explain the experimental evidence by which each law has been developed; and, by avoiding mathematical details,—while accepting the proofs they afford, —to place clearly the deductions from physical investigation before those to whom the higher-class treatises are sealed books, to which it is hoped the Elementary Physics may prove an appropriate introduction.

CONTENTS.

CHAPTER I.

Page.
GENERAL PROPERTIES OF PONDERABLE MATTER 1
Vignette. Gravitation.—The Plumb-line and Level.

CHAPTER II.

GENERAL LAWS OF MOTION 79
Vignette. Moving Powers.—The Lever, Wedge, Pulley, and Wheel and Axle.

CHAPTER III.

LAWS OF SLIGHTLY ELASTIC FLUIDS 104
Vignette. Elastic Fluids.—Water-wheels, &c.

CHAPTER IV.

LAWS OF ELASTIC FLUIDS 134
Vignette. Pneumatics.—Air Balloon, Force of the wind.

CHAPTER V.

SONOROUS MOVEMENT OF BODIES 176
Vignette. Sound.—Speaking Trumpet; fishermen hailing.

CHAPTER VI.

Page.
PRIMARY PHENOMENA OF ELECTRICITY 199
Vignette. ELECTRICITY.—Thunder Storm.

CHAPTER VII.

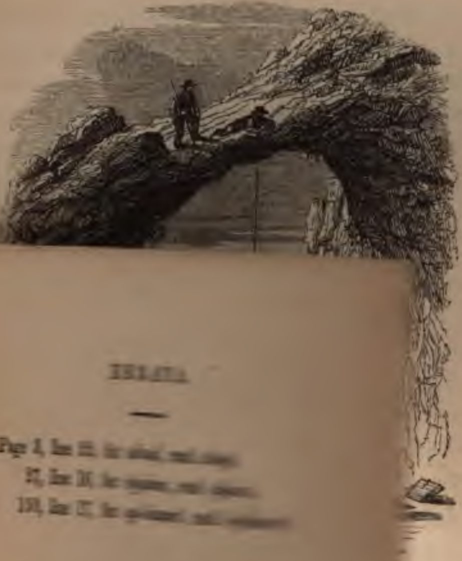
HEAT, OR CALORIC 331
Vignette. HEAT.—Volcanic Eruption. The setting Sun.

CHAPTER VIII.

LIGHT AND ACTINISM 379
Vignette. LIGHT.—The Rainbow, Primary and Secondary.

TABLE OF SPECIFIC GRAVITIES 453

INDEX 457



ERRATA

—

Page [illegible], line [illegible], for [illegible] read [illegible].
[illegible], line [illegible], for [illegible] read [illegible].
[illegible], line [illegible], for [illegible] read [illegible].

GENERAL PROPERTIES OF PONDERABLE MATTER.

COHESION.—*Attraction at insensible distances.* If we break a stone from the mountain mass, and inquire into its constitution, the earliest fact with which we shall make ourselves acquainted will be, that, by the application of a certain amount of force, we can reduce that stone into minute fragments. Each of these may, by the continued application of mechanical force, be crushed into infinitely smaller particles, and we may, by continuing to beat or grind the mass, reduce the whole into a powder sufficiently fine to be dissipated by a breath, and float almost invisible on the air. We learn from this that the mass of the mountain is made up of exceedingly fine particles of matter, held together by some peculiar force; and—since the rocks of the mountain fairly represent the solid crust of the Earth—that our planet is an accumulation of infinitely fine dust aggregated to form a globe. If we select our example from the organized forms of creation—the wood of a tree, the leaf of a flower, the bone from an elephant, or the muscle from an ox—we may dry them and reduce them all alike to an impalpable powder. Dust they all are, stands recorded as a universal truth.

A discussion has been continued from the earliest periods to the present time on the question—Is matter infinitely divisible? or are there limits beyond which matter can be no further divided?

It has been proved, particularly by the examination of the truly illustrious Boyle, that twelve grains of silk as spun by the silk-worm will measure a mile; an inch, therefore, of this delicate fibre, which is very appreciable to our senses, will weigh considerably less than the five-thousandth part of a grain. Again, the extreme thinness to which gold can be beaten is a remarkable example of the extension of matter, and several applications of this metal in manufacture afford us very striking evidences of the extreme divisibility of a solid body. Gold-leaf can be made so thin that fifty-six square inches will weigh but one grain; and the gilding on silver-wire, as used for making bullion fringe, is so attenuated that less than the hundred-thousandth part of a grain is visible to the naked eye. Chemistry affords us numerous curious examples of still more extreme division. A grain weight of mercury may be dissolved in an acid, and this solution mixed with four or five gallons of water, and in every drop of this water the indications of mercury may be ascertained. One grain of this metal has, therefore, been divided into more than 200,000 parts, each one of which can be rendered evident to the senses by appropriate tests. Cerulin, the colouring matter of indigo, is of so intense a blue that a single grain of it will impart that colour to two or more gallons of water. We can see so small a quantity as the thousandth of a grain of water, and distinguish this blue colouring matter in that small quantity: this proves the division of a grain of cerulin into 50,000,000 of parts, and, were our senses more perfect than they are, we should be able to ascertain, without doubt, that this division of matter might be carried much further.

Opposed to the view that matter is infinitely divisible stand the facts of chemical science. The beautifully harmonious laws which prove to us that material substances always unite in definite proportions, appear conclusive as to the existence of an ultimate *atom*. Although we are not able, even by the aids which ingenuity has given to our senses, to reach this ultimate atom, the only inference to be deduced from the study of chemical combinations, is, that all matter consists of certain small parts which will not admit of further division, the sizes of which the human senses are incapable of determining.

Having learnt that to every one of these atoms belongs a power, in virtue of which they aggregate to form masses, we have to proceed to the investigation of the principles upon which this power depends, the laws by which this force is exerted, and to the examination of certain other powers which are discoverable in action throughout nature. This constitutes the branch of science which we call Physics—a term derived from the Greek φύσις, *nature*.

We often use the word Physics without that exactness of meaning which is desirable in a name by which we would indicate one of the most important divisions of human knowledge. In its enlarged sense it is supposed to comprehend the study of all nature, embracing every branch of inductive philosophy, experimental research, and the sciences of pure observation. In its more limited signification it is employed to express the study only of the great forces or powers which are known to influence the conditions of the material universe; or, rather, of the laws by which these agents of creation are regulated. In this last sense it is employed in the present treatise.

That no misunderstanding of the meaning intended to be attached to the term may arise, it is necessary to repeat that Physics is, in this volume, limited to the study of *those conditions of matter*, not dependent on chemical combination, *which we perceive around us, and of the operation of those subtile agents which have been proved by science to be ever active in producing those conditions.*

Since it is also important that particular terms employed in treatises on Physics should be clearly defined, it will be found useful in the first instance to determine our nomenclature.

Matter, and the physical agents which are so essential to its existing conditions, becomes known to us only through the medium of the senses. Matter exists in different states, as, for example :—SOLID, as in a mass of metal or a stone. PLASTIC, or *semi-solid*, as in pitch, which, although it presents the appearance of a solid, will be found to be continually changing its form by the movement of its particles, when left free to move: this condition is thought by some to belong to the ice accumulated in those great natural formations, the glaciers. FLUID, as in water. As the term *fluid* is applicable to all flowing bodies, and therefore used with equal correctness when applied to vapours or gases, LIQUID appears more appropriate when we desire to speak of a body like water. VAPORIFORM, as in steam, the vapours escaping from volatile spirits, and such like bodies. GASEOUS, as atmospheric air and the gas employed so extensively for street and house illumination.

These conditions are rendered evident to human sense principally through the channels of the eye and the hand.

The eye distinguishes the letters on this page, from the circumstance that the white paper *reflects*, or sends off to the eye, nearly all the light which is now falling upon it; whereas the matter which composes the ink in which the letters are printed absorbs most of the light it receives, or, at least, the letters appear black because they do not reflect light enough to act on the optic nerves. Thus, we distinguish material nature by the varying powers which every substance possesses of acting upon light according to a definite law—throwing back more or less of this luminous principle to act upon the organs of vision. In this way we obtain our ideas of *size*, *form*, and *colour*; and also of *opacity* and *transparency*.

The hand, as the member commonly engaged in extending our knowledge by the sense of feeling, comes to aid the eye, and by it we ascertain that a body is *solid*—it will not yield to the pressure of the fingers;—that it is *plastic*, because it will yield, and we can mould it;—that it is *fluid*, from our being enabled to move the hand freely when it is immersed in it;—and the distinctions between the *liquid* and the *vapour* and *gas*, are principally determined by the conditions of resistance which these bodies offer.

Certain properties which are common to all matter are usually termed *essential properties*. These must be briefly enumerated, since a correct understanding of each particular term is necessary to the successful prosecution of the study of Physics.

Extension.—The capability of being spread out.

Divisibility.—The property of being cut, crushed, or powdered.

Impenetrability.—This term requires a more careful explanation. If a bullet is placed on a certain spot, we cannot place another on the same spot without displacing the first—we cannot force the two bullets into one of the same diameter. Some bodies are *porous*—as sugar, chalk, or sponge—and, if placed in water, that liquid appears to *penetrate* them; but it is only taken up into the pores—the vacant spaces,—no water enters the solid atoms of the substance. We may plunge the hand into a mass of sand: we do not penetrate the sand, we only displace it; therefore the particles of matter are said to be *impenetrable*, or to possess *impenetrability*.

Density.—Hardness and heaviness. Bodies differ very materially in the quantity of matter which they contain in a given space. A cubic inch of iron and a cubic inch of wood may be taken as examples. In the first, the particles constituting the mass are packed much closer together than in the last; it has, therefore, a greater *density*.

Inertia.—A body at rest cannot be moved without the application of a certain amount of force; the quantity of force applied, therefore, to move the body is a measure of its *inertia*—the force which keeps it at rest. Again, a ball is discharged from a cannon, or a plummet is swinging suspended from a long string; they are moving at a uniform rate: in stopping either the ball or the plummet we apply a certain amount of power to *resist* their movement.

The *inert* mass is moving in virtue of a force applied, and, unless some power is opposed to it, it would continue to move for ever, since matter is absolutely passive, and cannot either move itself, or bring itself to rest after it has been moved.

Gravitation is the force which belongs equally to the smallest atom and to the largest world, producing those attractions which bind masses of matter together, and keep planets in their regular orbits. It is the force which draws a small body, set free to move, to a larger one. A stone falls to the earth in virtue of the gravitating forces of the two masses, the earth and the stone. The *weight* of a body is the force necessary to balance the power of gravitation, or to keep it from falling to the earth.

To matter also belong many *accidental* or *secondary properties*, which are mainly dependent on the foregoing, as *Elasticity*, *Ductility*, *Strength*, *Stiffness*, *Toughness*, and *Resilience*.

The first division of this subject naturally relates to the condition of bodies at rest. Since every atom of matter is acted upon by several forces, either one of which acting separately would be sufficient to set it in motion, a body at rest, being, as it were, balanced between these powers, is said to be in *statical equilibrium*, and this division of Physics is termed *Statics*, which, in a strict sense, means the determination of weight only; but it is commonly and properly extended to a consideration of the influences of all those forces which can be compared with weights. We have also the term *Hydrostatics*, relating to the equilibrium of fluids, and *Hydrodynamics*, embracing the laws of fluids in action.

Dynamics is the science which belongs to matter in motion; a force, or power, undisturbed or balanced, is said to be a *statical force*, whilst in activity it is termed a *dynamical force*. It is not intended that these definitions should be supposed to have that logical accuracy which it is necessary they should bear in the refined philosophy which becomes in its nature almost metaphysical, and in which even some experimentalists are fond of indulging; they are, however, considered sufficiently accurate and precise for all the purposes of Elementary Physics. Without in any way advancing further than we have already gone into the consideration of the theory of atoms—a question which has exhausted much metaphysical ingenuity,—it is sufficient for our purpose of reading the great book of nature, that we admit the existence of the ultimate atom.

It is so important that the idea of an ultimate *point of matter* should be correctly entertained, that, returning to our illustration of the stone regarded as a portion of one of the great mountain ranges of the earth's surface, and consequently a proper example of one of the forms of matter, it is certain that the most minute portion of the powder to which we can reduce it still retains all those powers, forces, or agencies which are discovered in the entire mass of rock to which it belongs,—that, indeed, every particle of dust which is blown about by the winds is influenced by, and reacts on, those great agents of creation which we distinguish by the names of Gravitation, Electricity, Heat, and Light, under all their modifications.

Newton regarded the atom as hard and impenetrable, without elasticity; other philosophers have adopted the theory of its being infinitely elastic, and capable of penetrating, and being penetrated by, other atoms. It is, of course, impossible to *prove* which of those theories approach nearest to the truth. All the ends of our inquiry appear to be answered, however, by regarding the atom as an *elastic* sphere surrounded with an infinitely extensible set of influences or properties, by which it is enabled to unite with other atoms to form a mass.

To convey to the mind a correct idea of the powers at work to arrange the mass constituting this world, let us place upon a horizontal disc, capable of being made to revolve rapidly, a ball of some loosely adherent powder, say of chalk, or flour. (We cannot remove any substance

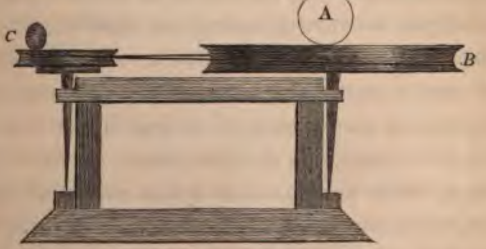


Fig. 1.

entirely from the influence of the great natural forces, we therefore only approach the actual conditions.) While at rest, our little globe of dust A—let us regard it as a mimic world—will retain its form; but if our whirling board B is set into rapid revolution by turning the smaller wheel C, the particles at once begin to separate, the sphere flattens and spreads itself over the disc, and if the motion is rendered sufficiently rapid our miniature globe will be dissipated, the particles of which it is composed being thrown off in curved lines in every direction.

The Earth upon which we live is revolving on her axis at the rate of upwards of 1,000 miles an hour, and is impelled onward in her orbit with a velocity of more than 68,000 miles in the same time. We have never yet attained, on our railroads, to the speed of a hundred miles an hour, therefore the locomotive carriage imparts but a very imperfect idea of the immense velocity of either of these motions of this planet. But, for illustration, let us suppose that the vapour force which is employed to turn the great driving-wheel of a locomotive, is made to set an artificial globe in revolution at an immense velocity, and to bear it onward at a speed sixty-eight times greater than that at which the ball revolves: it will be readily conceived, supposing our ball to be made of loosely coherent matter, that it would break up into dust, and be seen as a train of fine particles trailing out behind the moving engine. That this is the result of motion on our most solid bodies, may be proved by fixing two hoops of any

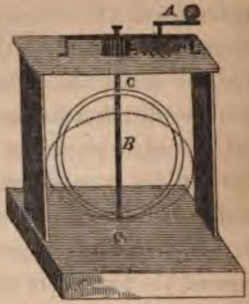


Fig. 2.

metal transversely on an axis B, firmly at the point C, being left free to move at *c*. On turning the handle A so as to give those metal circles a very rapid motion, it will be observed that they will bulge out, and that the upper, the loose, ends of the hoops will descend upon the axis, proportionally to the velocity imparted to them,—thus representing a flattened spheroid. If two balls are attached by a cord to a rod, and the rod turned by rolling it between the hands, we have a very simple illustration of this tendency of the particles of matter to fly off from the centre when they are put in rapid motion. This arrangement is most usefully employed in the steam-engine. The balls are connected with the valves, and, opening as the speed increases, they contract them, and thus regulate the quantity of steam admitted to act on the piston.—We occasionally hear, when by some casualty the steam-engine is suddenly relieved from the work it is employed to do—or, as it is called, has lost

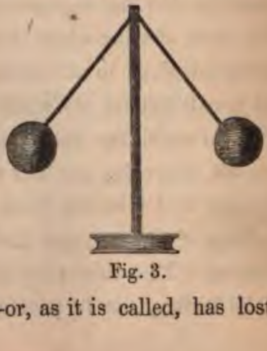


Fig. 3.

its load,—that the fly-wheel is rent to pieces, owing to the enormous velocity it thus acquires; a striking example of the fact, that motion may become sufficiently violent to break up the closest aggregation. The Earth is itself an example of the operation of this force. Its diameter at the equator is about seventeen miles greater than its polar diameter. It has been thought by some, that a plastic condition was necessary to produce this result, and that the form of our planet was determined when it was yet in a semi-fluid state. This does not appear necessary to the conditions, it being proveable by experiment, that the motion of the earth may produce a disturbance in the dense mass of which it is constituted quite sufficient to occasion this bulging out of the revolving sphere. It may appear difficult to conceive how light bodies, free to move, are not thrown off from the surface of the earth into space, under the influence of motion. It will be shown that the power of gravitation is so nicely balanced against the result of the earth's revolution, that the lightest down floating on the air swims in the calm equilibrium of two forces apparently undisturbed. The alterations produced in the form of bodies by motion, can be very prettily studied by an ingenious contrivance employed by M. Plateau, in his researches on the form of bodies when relieved from the

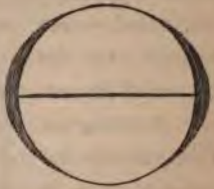


Fig. 4.

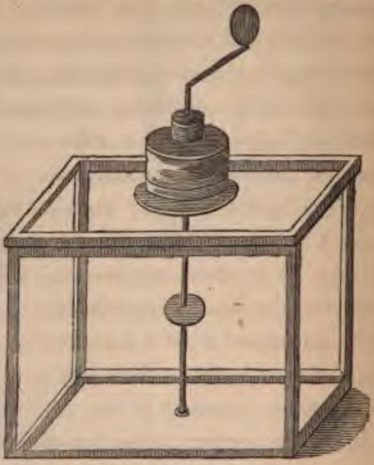


Fig. 5.

influence of gravitation. A top is adjusted to a glass box or jar, so that a wire, connected with an arrangement for turning it at any moderate speed, passes through to the bottom of the vessel. A mixture of spirits of wine and water is made, in such proportions that the fluid is of the same specific gravity as olive-oil. This is easily effected by the use of the oil itself: oil will float on the surface of water, but will sink to the bottom of rectified spirits; therefore, if we pour a portion of spirits of wine into the glass, and put in a globule of oil, the spirit will float above it, and it will be observed that the oil, influenced by attraction of the earth and surrounding masses, is a more or less flattened spheroid; but if we add a little water, and mix it carefully with the spirit without breaking the floating mass of oil, it will be seen to swim higher up in the spirituous medium and present less flatness. By carefully adding water in this way we eventually bring the oil into the very centre of the fluid, and it will now be seen to be a perfect sphere. Thus far the experiment is most instructive, showing the influence of the power we call Gravitation on the form of matter. The wire being now passed down through the sphere of oil, we turn the handle slowly, and we have immediately a flattened spheroid, which will become more so as we increase the speed, until it spreads out into a sheet of oil still held by the revolving wire. If the rate of revolution is still more increased, we have a very remarkable result—*a ring of oil* separates from the rest, which, although there is no apparent connection between it and its centre, still moves at a uniform rate with it: thus giving a miniature representation of the phenomenon of the ring of Saturn.

In these results we have conclusive indications of a power by which matter is aggregated or collected into masses—of a force acting in opposition to the force belonging to motion. It is necessary that we should disregard, for the present, any of the influences beyond those of motion and this binding force, since the phenomena are rendered more complicated by admitting them in the present stage of our argument.

The atoms of matter are held together by a power which we call COHESION, Cohesive Attraction, or Aggregative Attraction, and which must be regarded as attraction acting at distances which are not measurable, or, as they are termed, *insensible distances.*

Many examples of the operations of this force are readily obtained. Press closely together two perfectly clean and flat pieces of plate-glass, and they will adhere with considerable force. Cut a piece of lead uniformly in two with a sharp instrument, bring the two pieces again together with a twisting motion, and they will now support many pounds weight before they can be again separated. Plates of iron are scraped so perfectly true, that they adhere with great force; and this power is sometimes made of practical utility in the arts. It may be thought to be due in some measure to the pressure of the atmosphere; but when, by means of the air-pump, this influence is reduced almost to nothing, the adhesive force still continues. By hanging discs of metal or other bodies to one end of a scale-beam, and bringing them to rest upon the surface of water, or any fluid, we may relatively ascertain the force of cohesion exerted between them. The attractive force existing between discs of solid metals of the same diameter and mercury, according to the experiments of Guyton-Morveau, is as follows:—

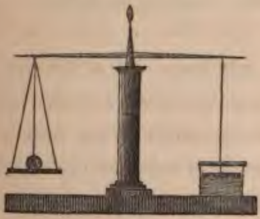


Fig. 6.

Copper	140 grains.
Iron	150 ,,
Lead	317 ,,
Tin	418 ,,
Gold	446 ,,

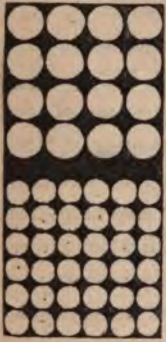
That is, the number of grains specified were required to remove the discs from the surface of mercury.

If we suspend a disc of glass upon the surface of water, and ascertain that a certain weight, say 100 grains, is necessary to remove it—to break the cohesion,—we shall find, if we substitute other fluids, such as ether, spirits of wine, turpentine, or any of the oils, that the weight required will constantly vary. We thus, to a certain extent, obtain a measure of the cohesive force with which the particles of fluids are held together; and by rending metal bars by hanging weights to them, or by applying any force of which we can obtain a correct measure, we arrive at similar approximate results.

We are thus taught that some *cause* is in action, the visible effects of which we call *Cohesion*, binding the atoms of which the earth is formed, into a sphere, which, however, by the action of motion, is reduced to a flattened spheroid. We learn that this force acts with different degrees of intensity in different masses—this being regulated by some physical causes at which we have not yet arrived.

All forms of matter are constituted of minute atoms, held within certain immeasurable distances of each other by this cohesive or aggregative power. We therefore suppose that the number of atoms contained in the same space differs in dissimilar substances—that a cubic foot of air is made up of a smaller number of these atoms than the same measure of water, and that a solid contains a

FLUID.



SOLID.

Fig. 7.

much larger number than exists in the same space in a fluid body. The annexed diagram will convey an idea of this hypothesis. Notwithstanding our boasted advances in science, we have scarcely arrived at any satisfactory knowledge of the powers which regulate the internal conditions of masses of matter. The *molecular forces* are almost entirely beyond our perceptions, and our ignorance of the laws by which they are regulated should teach humility to the most exalted human intellect.

A peculiar attractive power resides in every particle of matter: this is in perfect independence of the operation of any modification of electrical force. A few curious instances of various modes in which this power manifests itself, will prove instructive. Charcoal exhibits a power of condensing about its particles, or within the porous spaces of its mass, fluids, both gaseous and liquid, in a very remarkable manner. If a piece of charcoal, from which all the air and moisture have been expelled by heat, is plunged into any of the following gases, it will be found that the absorption is as stated below.

Ammoniacal Gas . . .	90	times its volume.
Muriatic Acid	85	,,
Sulphurous Acid . . .	65	,,

Sulphuretted Hydrogen .	55	times its volume.
Carbonic Acid	35	,,
Carburetted Hydrogen .	9·42	,,
Oxygen	9·25	,,
Nitrogen	7·5	,,
Hydrogen	1·75	,,

We thus learn, since the volume of the body absorbed is so much greater than the volume of the absorbing body, that the gas or liquid must be subjected to a compressing or condensing force of enormous activity.

Again: spongy platinum possesses a similar power; and when a stream of hydrogen gas is projected upon it, the pores of the platinum holding already, in a condensed form, atmospheric air, the hydrogen is forced by this molecular agency into such close contact with the oxygen, that chemical combination results, with the development of heat and light. Nor is this quality confined to the pulverulent form of this metal; for if a piece of *perfectly clean* platinum foil, washed in nitric acid, to remove organic matter from its surface, be plunged into a mixture of oxygen and hydrogen gases, this mechanical force is exerted to such a degree, that they combine to form water, which is condensed on the metal as a dew, and, as in the other case, we have the manifestation of both heat and light, the platinum becoming glowing red-hot. These very remarkable phenomena, which are now found to prevail in all porous bodies, soils, sand, &c., have been referred to a power called by chemists *Catalysis*, or the action of presence. (A familiar illustration is given in the fermentation of bread:—a small portion of yeast, a body in a fermenting state, is placed in a large quantity of moistened flour, and fermentation is established through the mass.) But evidently we must seek an explanation of the above effects in some other direction, for results which have been referred to a common origin have evidently nothing in common.

A peculiar force has been observed as if residing on the surfaces of bodies; the operation of the attraction of all those particles of matter which constitute the outer layer of the mass. This force, or these forces, have been termed *Epipolic*, which means no more than the action of a surface. The instance given of the platinum foil is evidently to be comprehended within the phenomena of epipolic force; and so, we believe, must be the power of condensation so remarkably shown by charcoal, and those similar actions, which, although varying in degree, can be traced to every solid body.

Let us not deceive ourselves, and suppose that by adopting a name we have explained the cause; we merely employ it for the purpose of grouping together a singular variety of observed effects, the cause of which has hitherto eluded our research. No doubt, however, but it belongs to those hidden powers which regulate cohesion; and *Capillarity*, or the ascent of fluids in capillary tubes (tubes having hair-like bores), is the exertion of the same force.

A moistened sponge, or a lump of sugar, being placed on the surface of water, becomes rapidly charged with the fluid, owing to its ascent through the capillary tubes to these substances. In sugar the tubes are so small that the water will thus ascend to an almost unlimited height. If we take a series of glass tubes, of very fine bore, but of different diameters, and place them in a vessel of water—which should be coloured to show the result more strikingly—we shall see that the water will rise the highest in the smallest tube, and that the height will gradually diminish as the size increases. The height at which the same fluid will rise in any given tube is always uniform, but it varies for different fluids. We have already shown that the cohesive powers of dissimilar fluids are not alike, and this capillary ascent is due entirely to the same cause. From very careful experiments it has been proved that, supposing sulphuric acid stood at a given point in a tube, which we will call 1, the relation of other fluids will be as follows:—

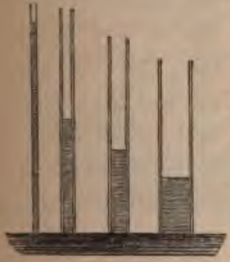


Fig. 8.

Sulphuric Acid	1
Pure Alcohol	1·8
Nitric Acid	2
Oil of Turpentine	2·5
Pure Water	3·3

The same result may be produced by two plates of glass touching at one end, but slightly separated at the other. When this arrangement is plunged into water, the fluid rises and forms a curve—the well-known hyperbola—as shown in the woodcut. That this depends entirely upon the action of the force producing cohesion is shown by employing a rod, or a single plate of glass, and placing it steadily in a vessel of water: we shall perceive, after the whole has been allowed to remain free of any disturbance, that the water will rise to a higher level on all sides of the glass than over any other part of its surface.

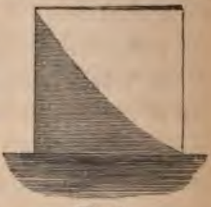


Fig. 9.

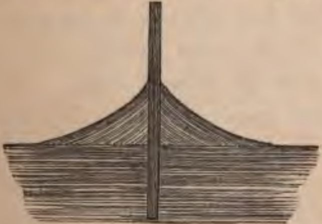


Fig. 10.

This superficial cohesion of liquids may be expressed, approximately, by weight. Every inch of the surface of water is stretched each way by a force equal to the weight of $\frac{1}{100}$ part of a cubic inch of water, which is two and a half grains. According to Dr. Young, "thus if a solid of any form, of which the surfaces are vertical, and which is capable of being wetted by either of the fluids—water or mercury—be immersed into a reservoir containing it, the fluid will be elevated around it to such a height that two grains and a half of water, or seventeen grains of mercury, for each inch of the circumference of the solid, will remain above the general level of the reservoir." This force is exerted in different degrees, and, indeed, the mass which attracts one fluid may have a repellent power for another. Glass attracts water—that is, the attraction of cohesion to the glass is greater than the attraction of the watery particles for each other; but the attractive force of glass for mercury is less than half as great as the mutual attraction of the particles of mercury. Hence, if we place a glass plate in mercury the metal is depressed (fig. 11); and mercury, being placed in a dense glass vessel, becomes convex on its surface (fig. 12). A glass rod or plate attracts water, and that fluid is elevated around it; but if we grease the glass it will repel the water, which will exhibit a similar depression to that shown in the case of mercury. This metal will not flow through fine muslin, nor water through a fine sieve, the wires of which have been

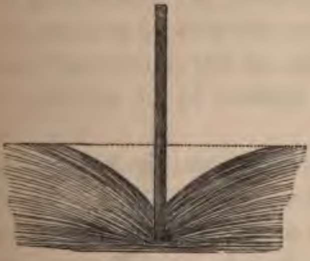


Fig. 11.

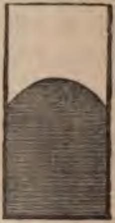


Fig. 12.

greased, and if the hand is dusted with *Lycopodium* it may be immersed in water without being wetted, showing the extent of repulsion which is exerted between the particles of the fluid and the solid body.

It may be shown that this cohesive or capillary force is sufficient to restrain the escape of vapours. If we place in capillary tubes (open at both ends) as much water as they will support by this power, they may be kept under the influence of full summer sunshine without losing any of the water by evaporation.

This attraction, or adhesion, or a corresponding repulsion, is exerted between the particles of all gases and liquids as well as solids, and there is little doubt but the solubility of bodies is regulated by the operation of this power.

A few experimental illustrations will fairly put these facts of adhesion before us.—

All gases, under any circumstances, when placed together, diffuse themselves through one another and form a uniform mixture. If two bottles be connected by a glass tube, and the lower bottle filled with heavy carbonic acid gas, and the upper one with light hydrogen gas, a portion of the heavier gas will after a few hours be found in the upper vessel.

If a vessel (fig. 13) is filled with gas and placed in a horizontal position, and the communication with the external air is effected by means of a bent tube, which can be turned *downward* when the gas is *lighter* than air, and *upward* when it is *heavier*, the gas will gradually escape from the cylinder, and its place be supplied with atmospheric air. The rate of this *diffusion*, according to the experiments of Graham, is as follows for 100 volumes of gas:—

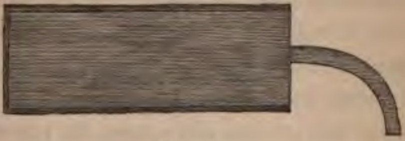


Fig. 13.

SP. GR.				
1	Hydrogen . .	(in four hours)	81·6	volumes.
8	Light Carburetted Hydrogen	,,	43·4	,,
8·5	Ammonia . . .	,,	41·4	,,
14	Olefiant Gas . . .	,,	34·9	,,
22	Carbonic Acid . .	,,	31·6	,,

From which it appears they escape more quickly the lighter they are. It was found that 47 measures of hydrogen escaped in two hours, and the same volume of carbonic acid in ten. It may not at the first appear how this is referred to adhesion; but when we recollect that the denser body has a power of drawing a less dense one to it, we shall perceive that atmospheric air attracting the particles of the lighter hydrogen, is the same in character, to some extent, as charcoal condensing fluids in its cells, but the air, being mobile, flows in to supply the place of the body drawn out. If two gases, having different rates of diffusion, are mixed—say hydrogen, diffusing at the rate of 80 measures in four hours, and olefiant gas at the rate of 34 measures in the same time—and the vessel containing them is placed over one containing carbonic acid, it will be discovered after a period that the hydrogen has left the olefiant gas, and it will be found with the carbonic acid in the lower vessel. Here the heavier carbonic acid attracts, and compels the adhesion of the lighter hydrogen gas.

The consequence of this law is, that the great atmospheric envelope of this planet is kept always in the same state;—those noxious exhalations which are constantly arising from the operations of animal life and from the decomposition of organic matter, and those gases which are continually being poured out during many of the processes of manufacture, and which would lodge near the surface of the earth in virtue of their gravity and of the attractive force of the solid surface of this sphere, and thus produce an atmosphere which would be destructive to life, are diffused through the whole extent of the air, and by dilution rendered harmless, until they are removed by the operations of chemical forces which resolve them into new forms of matter.

It has been shown by Professor Graham that the same phenomena of diffusion hold through all liquids; and all soluble salts appear to be mutually diffusible, but with different rates. The diffusibility of a variety of substances has been carefully examined. The following are some of the results, 20 parts of the substance being always employed in 100 parts of water. It should be stated that the salt of which the rate of diffusion is to be ascertained, is contained in a wide-mouthed bottle, which is placed in a large vessel of distilled water, through which it diffuses, the rate being ascertained by examining, at given periods, the quantity of the saline matter in any portion of the entire mass of the liquid.

The quantities diffused are expressed in grains:—

Chloride of Sodium (Common Salt)	58·68.
Sulphuric Acid in water	69·32.
Sulphate of Magnesia	27·42.
Crystallized Cane-Sugar	26·74.
Starch Sugar	26·94.
Gum Arabic	13·24.
Albumen	3·03.

The remarkably low diffusibility of albumen may be traced to a provision for retaining the serous fluids within the blood-vessels in the living organism.

When salts having different rates of diffusion are combined, they diffuse out into the surrounding watery atmosphere according to their own rates, thus breaking up chemical combination.—A pleasing example of this is afforded by thebeautiful blue solution, ammonio-sulphate of copper. This deep-coloured fluid being placed in a watery atmosphere, parts first with its sulphate of ammonia, leaving behind in the vessel a pale blue sulphate of copper;—as we see the rich colour of the solution fading, we may detect the sulphate of ammonia in the water, and satisfy ourselves at the same time, that no sulphate of copper has escaped. In this way, no doubt, many important chemical decompositions are constantly taking place in nature.

A few remarkable cases of the action of adhesion between solid, but slightly porous substances, and fluids and gases, remain to be noticed. These are usually embraced under the terms *exosmose* and *endosmose*, an impulse varying in degrees of force. When two liquids capable of mixing are separated by a porous diaphragm, each of them permeates the diaphragm to mix with the other, but not at the same rate. If we tie a wetted bladder over the mouth of a glass funnel, and, having filled it to a certain marked line with a solution of table-salt, place it, inverted, in a vessel of water, so that the level of the fluids in each exactly corresponds, the water will flow in through the diaphragm, and elevate the saline solution considerably, while the level of the water is lowered: at the same time some of the salt passes out of the funnel and mixes with the water; but the current flowing in is much the strongest, and hence named by Dutrochet the *endosmose* current, the weak one circulating outward being the *exosmose*. Endosmose proceeds from water to all kinds of salts, increasing in force with the strength

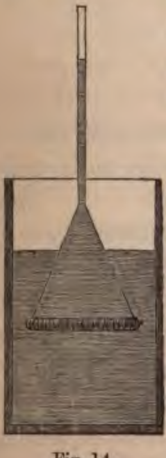


Fig. 14.

of the solution; it diminishes as the solution becomes diluted, and ceases when the two fluids become of uniform density. From water the rate of endosmose varies to different salts, it being strongest towards the salt at the head of the following table, and weakest towards the last on the list.—

Chloride of Copper,
Sulphate of Iron,
Sulphate of Copper,
Muriate of Soda,
Muriate of Ammonia,
Chloride of Iron,
Cyanide of Potassium.

With Protochloride of Tin, Nitrate of Silver, and Chloride of Gold, when animal membrane is employed, no endosmose occurs, owing to the mutual decomposition of the salt and the organic matter.

With caoutchouc, porous earthenware, baked clay, plaster of Paris, and many other bodies, these impulses have been observed. The same general law is maintained in all cases, the order or rate of endosmose varying with the adhesive force of the solid employed, for the liquids or gases with which it is in connection. A caoutchouc bottle, filled with ether and *carefully closed*, gradually empties itself if placed in alcohol or water—if filled with alcohol it distends itself in ether, but empties itself in water—if filled with water it distends when placed in either alcohol or in ether.

If a glass filled with alcohol is tied over with a bladder and placed under water, it swells up to such an extent, that when the membrane is pricked with a needle, the alcohol spirts out in a long stream.

If a bladder containing equal parts of alcohol and water be hung up in the air, the water will gradually escape through the membrane, leaving the strong spirit behind. In the same manner, if proof spirit is placed in a wine-glass covered with bibulous paper, the water escapes and the spirit increases in strength.

The importance of these conditions of matter are peculiarly exhibited in the animal economy. It is manifest that all nutriment taken up by the body, reaches its interior by passing *through* animal membrane in the fluid state. The food we eat passes first by the mouth and œsophagus to the stomach. The thick sheathing of the throat does not admit of the passage of fluids through it. In the stomach, however, and the intestinal canal, the membranaceous linings allow of endosmose action, and this is, in consequence, energetically going on within us. A consideration of these phenomena operating to produce the due distribution of the necessary matter to supply the waste of the animal system, forms a most instructive exercise for the mind, and proves to us the extreme simplicity and beauty of an arrangement, by which one of the most exalted of natural phenomena is produced.

By this peculiar property of matter we may also explain some of the conditions which belong to the distribution of springs, these being in many instances due to an endosmose action, set up by a porous mass of earth or clay. If we divide a vessel with a wall of clay, and place pure water on one side of it, and saline water on the other, their respective levels will be very speedily altered; and this is more decidedly the case, if the arrangement is included within a voltaic circuit.

Heat acts in direct opposition to all these modifications of adhesive or cohesive force, and its tendency is to separate the particles of matter as far as possible.

With this knowledge of the influence of *caloric*,—as the cause of heat is called,—we can understand that liquidity and solidity are due to the lateral adhesion of the particles of matter; this adhesion, regulated by calorific repulsion, being always proportionate to the degree of solidity.—In a liquid the particles are so loosely adherent that they move more freely around each other; whereas this freedom of movement is not discoverable in a solid.

When a solid is extended or bent, it is clear there must be a disturbance of the particles, although the force applied may not be sufficient to destroy the cohesion. A metal bar which has its particles arranged thus—A, fig. 15—is extended—let us suppose drawn out into wire,—we may infer that these spherical particles are more or less extended, as B.

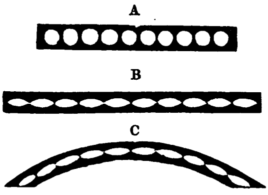


Fig. 15.

They adhere laterally, but they are drawn out of their original form. A similar disturbance of the arrangement would take place upon bending the bar, as at C: the large portion of the particles on the outside of the bar would suffer extension, whereas those on the inner circle would be compressed. If we pass the limits of adhesion between the particles, they fly asunder—the body is broken—cohesion is overcome by mechanical force. It appears probable that in all bodies there is an arrangement of particles in a definite order. The molecules, or primary masses of atoms, of different strata have been thought to be variously formed, and in obedience to their order of formation their order of arrangement and aggregation occurs. This scarcely admits of direct proof, but we have numerous indications which would lead us to believe that such may be the case, even in sedimentary deposits. A body in a liquid or semi-liquid state being allowed to arrange itself slowly into the solid form, acquires a very symmetric order of arrangement—it *crystallizes.* The metal bismuth offers a very beautiful example of this; but any of the metals cooling slowly will exhibit a crystalline structure. It is probable that the little sphere, the ultimate atom, attracts with varying degrees of force along different lines. As our earth has magnetic poles, and exhibits lines of varying intensity of attractive energy over its large surface, so may the little unit of matter have a polar disposition, and, in obedience to this, the tendency of the other atoms to adhere along defined lines, as is

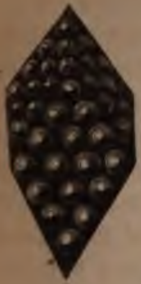


Fig. 16.

endeavoured to be shown in the annexed woodcut, which arrangement applies to any other form of crystalline structure. It must, however, be understood, that we yet want the proof that this force is magnetism; the illustration is intended to be merely analogical.

Mr. Brunel has proved, that if we break a bar of iron by a series of dull heavy blows, it will present a fibrous structure, as though it was a bundle of wires bound into a bar. Here we appear to have the condition of the slow drawing out, and alteration of the form of the atom; each one clinging to the other, as we have supposed them to do in the wire. If the same iron is broken by a very sudden blow, the fracture is crystalline; the rapid disturbance has at once destroyed the adhesion of the atoms along the weakest lines, or those at which the molecules unite together. This fact appears to show that we are not to conclude, because a substance breaks with an irregular fracture, that the arrangement of its particles is irregular.

Every solid body is either *amorphous*,—that is, formed by the mere aggregation of particles into a mass,—as sandstone, marble, clay, and such like bodies; or *crystalline*, as the diamond, quartz, Iceland spar, &c.; and yet it must be remembered, that both conditions result equally from the action of the adhesive forces which we have been considering.

Many bodies are known to exist in both states. *Carbon* is amorphous in coke and lamp-black, it often approaches to a crystalline form in graphite, and is beautifully crystallized in the diamond. *Sulphur* is sometimes in one and sometimes in the other condition. These curious phenomena belong particularly to the physics of chemistry, and are only mentioned in this place for the purpose of directing attention to the consideration of the different states in which we find ponderable matter, it being important that the mind should be fully impressed with the differences in arrangement, indicated in particular cases of inorganic and organic formation, as they are presented in nature.

If we take a section of the crust of the earth in any of those districts in which the rocks are of that description which would be formed by the slow deposit of matter carried by rivers, or otherwise, into a sea or lake,—as, for instance, in the sandstone districts of our own country,—these rocks, although presenting lines of deposit, disturbed and often contorted by some movement during, or subsequent to, their formation, present an amorphous condition; and even the igneous rocks, which have been forced through

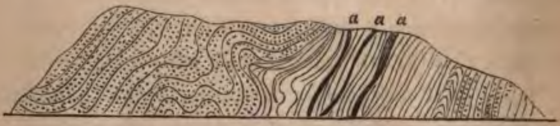


Fig. 17.

the sandstones, as at *a*, *a*, *a*, in a melted state, are often an aggregation of particles, without any crystalline arrangement.

Where matter has been held in solution by water, as in the larger caverns and immense chasms of the earth's rocky shell, from which it has slowly passed into the solid form, it invariably assumes the crystalline disposition; and we have thus presented to us forms of exceeding beauty, observing the most perfect geometrical laws. Matter, also, which has been kept in a fluid state by heat, —held in solution, we may almost say, by that element,— and cooled slowly, by which the molecules are free to arrange themselves according to even the weakest forces, assumes the crystalline condition.

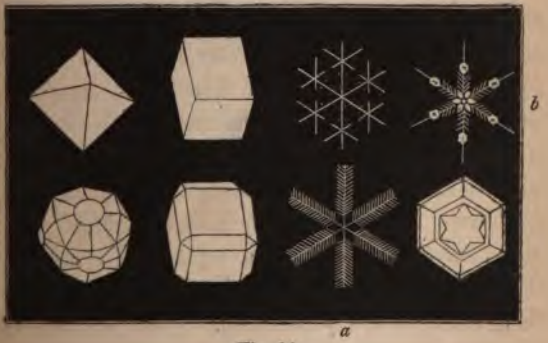


Fig. 18.

In the accompanying woodcut are represented several forms of crystals, into which we find earthy and metallic minerals arranging themselves, and also some of the very numerous, and always exquisitely beautiful, forms of frozen water, as exhibited to us in snow. In contemplating any of these, we cannot but be struck with the idea, that we see in these harmonious arrangements, the first indications of the process by which inert matter passes into an organized state and becomes a thing of life.

Such is the disposition of matter, when left to the impulsive power of those forces which appear especially to belong to its unorganized state. When, however, matter is, on the surface of the earth, subjected to the subtile influences of those principles with which light appears to be associated in the sunbeam, we have new forms and new sets of conditions.

As a simple illustration of organic form, let us select the leaf of a plant, and from it exalt our thoughts gradually through the scale of *living* creation to the most beautiful tree and flower, and from these, through the animal kingdom, up to Man, the intellectual interpreter of Nature's volumes; yet all of them alike the result of adhesive forces binding their particles into those masses, the forms of which are determined by other powers. Many have been disposed to regard the formation of leaves, particularly in the lower forms of vegetation, as being analogous to crystallization. When we observe the beautiful arborescent forms of crystallized water upon our windows after a frosty night, we can well understand how a superficial observer might be led to believe that this was the case, particularly when he sees such forms as *a*, *b*, Fig. 18, imitating the peculiar beauties of our fern vegetation. The conditions are, however, essentially different: a crystal, or any arrangement of crystals, is formed by the accretion of particles of matter on one nucleus, or on a series of atomic centres, which act and react upon each other—crystallization is the building up of a fabric by the adhesion of particles of matter to other particles already arranged in a geometric order, and we have easy methods by which we can thus greatly increase the size of any artificial crystals, by simply aiding the addition of fresh coatings of the substances of which they are constituted.

Fig. 19.

Organic arrangement,—whether we suppose the inorganic particles to dispose themselves into a cell by aggregation, and these again by aggregation into tissue; or that they arrange themselves in sheets, of which sheets the cells are subsequently formed,—differs from crystallization in the great phenomenon of vital power, the mysteries of which we are not permitted to know. A crystal grows by gathering matter from without—by collecting solid particles on its solid faces; a leaf grows by absorbing—breathing?—a gaseous element—by decomposing it in its cells (Fig. 20), and thus adding by assimilation to its structure, under the influences of life excited by light and heat.

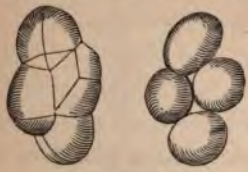


Fig. 20.

Dependent upon the operations of the attractive forces we have been considering, are the tenacity, ductility, and elasticity of bodies. The varying tenacity of some of the metals is well shown by the following results obtained by Professor Moseley.—

			Tons.
Wrought Iron in hammered bars has a tenacity per square inch of			30
Cast Iron	,,	,,	6
Cast Steel	,,	,,	44
Copper, cast	,,	,,	8½
Silver, cast	,,	,,	18
Gold, cast	,,	,,	9
Platinum	,,	,,	17

The same metals drawn into wires, owing to some peculiar alteration in the arrangement of their particles, exhibit a higher degree of tenacity. Calculations being made from experiments on wires one-tenth of an inch diameter, to bring it to square inches,—the following results appear:—

	Tons.
Iron wire	43
Copper wire	27⅓
Silver wire	17?
Gold wire	14

Tredgold applied a crushing force to one-inch cubes of matter, and ascertained the weight necessary to change their forms. These are some of his results:—

	Pounds.
Wrought Iron	17,800
Cast Iron	15,300
Brass	6,700
Tin	2,880
Lead	1,500
Oak timber	3,960
Ash	3,540
Elm	3,240

The most ductile of all bodies is gold: the extreme tenuity to which it can be beaten has already been mentioned. The most perfectly elastic body with which we are acquainted is glass, a thread of which can be bent repeatedly upon itself, and it will, when freed from the force applied, return again to its original form. The caoutchouc, or India-rubber, is a very familiar illustration of an elastic body. The elasticity of a spider's web is of another kind, since its fibres will admit of being twisted to almost any extent, without, in the slightest degree, exhibiting any tendency to regain their original position. These are examples of the exertion of the adhesive force under peculiar physical conditions; and it will be readily perceived that by ascertaining the extent of elasticity in a body we get a measure of its cohesive power—its strength. It is highly important to attend to this in engineering operations. A bar or beam of iron, forming a girder or bridge, has a determinable degree of elasticity. It may be bent to a certain extent, and when the force A is removed it will return to its original horizontality.

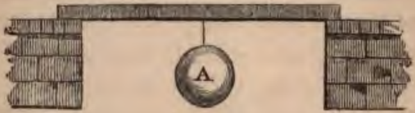


Fig. 21.

A slight force beyond this does not break the bar, but it will not return after flexure to its former state; it will take a *permanent set*, by which the limit of its elasticity is lessened, until eventually it is so far reduced as to break with a weight less than that which it was at first able to bear. This power of bars of any substance to reassume the form out of which they have been bent, is lost if the bar is kept for a prolonged period under a strain. A bow, for instance, of either metal or wood, will, if kept fully bent, refuse to straighten when freed from a restraint which has been long continued. We learn from this that the particles of matter, being forced out of their original positions in regard to each other, notwithstanding the exercise of the great force which is active in drawing them together, gradually assume new positions, and, the equilibrium being established, the whole remains permanently in its new form.

The *strength* of a body depends, therefore, upon some of those conditions of cohesion which we have been considering. The connection which exists between the particles constituting any body, may be broken by tearing, twisting, breaking, or by compression, or the application of a sudden blow, which last acts by vibration or tremor. The *absolute strength* of any body is determined by the force with which it resists being torn asunder when stretched lengthwise (Fig. 22); the *relative strength* is the force it opposes to *breaking,* this force being applied at right angles to its long axis (Fig. 23).

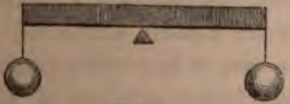


Fig. 23.

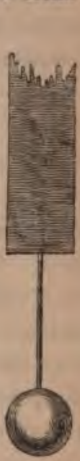


Fig. 24.

It must be understood that many apparently trifling conditions materially alter the amount of force necessary to destroy cohesion. For example, if the beam in Fig. 21 simply rests on both ends, a body suspended from the centre will break it, of only half the weight of that required to do so if the beam is firmly secured at both ends. These are points of the utmost importance in the practice of engineering and mechanics; but the mere indication of the fact is sufficient in this treatise.

We have now learnt that all matter, in whatever form we find it, is held together by a force which we call COHESION.

GRAVITATION.—*Attraction at sensible distances.* If the stone, the physical peculiarities of which we are considering, is thrown into the air, it falls back again to the earth. We have seen that each particle of matter clings to, is attracted by, and likewise attracts, other particles, and this force we call Cohesion, or Aggregation; and we learn that it is exerted with degrees of force, varying with the peculiarities of the particles, constituting the body. It is different for a mass of iron and a lump of chalk; there is a wide range in the operations of this force as exhibited in the mass of a granite rock and the mobile particles constituting the atmosphere. But it signifies not whether we throw a pound of iron or a pound of chalk into the air; they are each alike drawn back to the earth with the same velocity. The force is exerted equally upon all bodies without reference to their physical or chemical constitution, and by it, the disposition of earth, water, and air, in their positions relatively to each other, are determined.

The world upon which we live being nearly a sphere, it would appear to unaided reason, previously to the observation being made, that, supposing four men standing at the four cardinal points of the earth, east, west, north, and south, should suspend any heavy weights, left free to move, these weights must hang as is represented by the dotted lines and balls. If we fix four weights in this way to an artificial globe, the annexed diagram represents exactly what will happen. If, however, at *any part* of the great globe itself, we let free in the air any body, it will fall directly to the earth, and not only so, but it will tend towards the centre of the sphere, as is shown by the direction of the arrows.

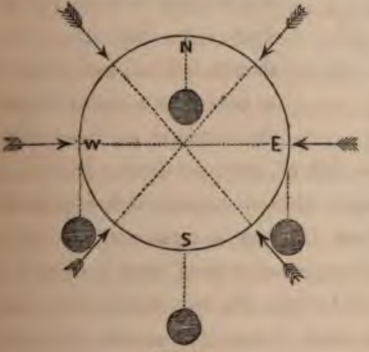


Fig. 24.

If a ball is set free from the hand it falls to the floor—this is a truth proved to us by every day's experience. What is the cause of this? Why does not the body, whatever it may be, fall off into the air? We should, in dwelling on these questions, remember that in the revolutions of our globe, with its oblique axis, our positions are altering relatively to the centre of the earth and the space beyond it,—that though at one period, standing at *a*, it would appear certain to us that a ball should fall to our feet, yet when at *b* the line of the fall is not so certainly indicated to the common idea. Again, that although to an ignorant man at *c* nothing is more self-evident than that the stone should fall to the earth, it is not quite so clear to him that a stone set free by the man at *d* should not fall off from the earth.

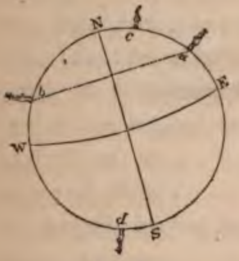


Fig. 25.

Were there not some restraining power, it is evident that a body projected from the earth's surface would not return to it. If, however, a ball is fired from a cannon, or a mass of matter is thrown off with still greater force during a volcanic eruption, to any elevation into the earth's atmosphere, it falls back again, along a curved line, to the surface. The power compelling this is GRAVITATION, some of the laws of which must now be examined.

If we place upon water, in a smooth pond, two floating bodies at certain distances from each other, they will be seen to approach, slowly at first, and eventually to rush rapidly together. If they are of the same size they will move at equal rates; but if one body is considerably larger than the other, the smaller of the two will be seen to move with the greater velocity, its rate being in an exact relation to the difference in mass between it and the larger body attracting it. In the same manner, two globules of mercury, placed on the polished surface of glass or iron perfectly level, move towards each other, and at last flow into one.

Cavendish instituted a very beautiful experiment for measuring the attraction of masses, which has been more recently repeated by the late Francis Bailey. This experiment consisted in fixing a large mass of lead in such a manner, that the amount of attraction exerted by it upon a light body was most accurately measured. From the determinations thus obtained—comparing the attraction exerted by the mass of lead for the lighter body (the relative weight and size of each mass being accurately known) with the attractive force of the earth,—these philosophers deduce that the mean density of our planet is, according to Cavendish, 5·48 times, and according to Bailey, 5·67 times, that of water.

The great law of gravitation, so fully developed by Sir Isaac Newton in his 'Principia,' is, *that every particle of matter is attracted by, or gravitates to, every other particle of matter, with a force inversely proportional to the squares of their distances.*

Upon this is founded those great deductions from observations by which it is proved that the planets of our system move around the sun as a focus, under the general influence of gravitation; the force by which the planet moves, varying inversely as the square of the distance from that focal point, or centre.

At the same time, we must not conceive gravitation as a power acting only from the centre of a mass; since every particle of matter has a gravitating power towards every other particle constituting the whole. By conceiving a single particle of matter drawing around it other particles by their mutual attraction, we shall see that the consequence must be a sphere. And Newton has shown, that a spherical body acting upon a distant mass, with a force varying as the distance of this body from the centre of the sphere, will produce the same effect as if each of its particles acted upon the same body according to the same law. A little careful consideration of the above diagram will aid the mind in comprehending this resolution of a number of small forces into one. The bodies of the solar system are nearly spherical: and it matters not whether they are of uniform density, or made up of layers greatly varying in density—these bodies act upon one another according to the sum of the attraction of all the atoms constituting the mass; and this force is exerted as if from so many centres of attraction. Thus, each planet acts upon the sun and on every other planet, with a force exactly proportionate to its mass, and inversely as the square of the distance between the centres of the spheres. This attraction is measured by the space through which it draws a body in a given time. The attraction of one body upon another does not depend upon the *mass of the body which is attracted*, but is the same, whatever

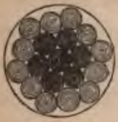


Fig. 26.

be the mass of the body so attracted, at the same distances. If the Earth and the Sun were equidistant from Jupiter, the influence of that planet would be the same on each, and would draw them through the same space in the same time. Again, this attraction is proportional to *the mass of the body which attracts*, if the distances of the different attracting bodies be the same. Supposing the Sun, which is very much larger than Jupiter, to draw the Earth through a given number of inches in a second, Jupiter, being at the same distance from the earth as the Sun, would draw it through a considerably smaller space in the same time.

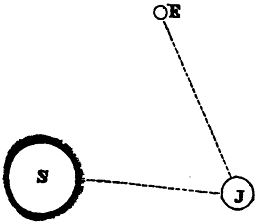


Fig. 27.

Throughout our own solar system—throughout the immense universe sprinkled with systems of worlds—this law of the action and reaction of gravitation knows no exception. The moon is held to the earth, and all the satellites are bound to their respective planets, by this force. The gravitating power of the sun chains all the planets of our system in their orbits; and the solar system itself is moving in a large orbit, under the attracting force of some centre far off in space, in obedience to this all-prevailing law.

It was shown by Newton, that the only curve in which a body could move, when acted upon by a force varying inversely as the square of the distance, must be a *conic section.*

As some notice of these curves must be continually recurring in the study of Physics, it is deemed advisable to explain them in this place. If we cut a cone perpendicularly to the base, the section is a *triangle* (1). If cut parallel to the base, it is a *circle* (2). If the section is made obliquely, the curve is an *ellipse* (3). If the section be made parallel with one side of the cone, the curve is called a *parabola* (4). If we cut the cone parallel to the axis perpendicularly from the vertex, making a greater angle with the base than is made by the side of the cone, the figure obtained is a *hyperbola* (5).

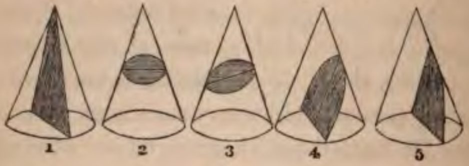


Fig. 28.

Supposing the sun's place to be at S (Fig. 29), and that a body was projected from A in a direction which would be the line A B, if independent of the sun's attractive force, it would, under the influence of that force, move in an ellipse, as A C D E, or some

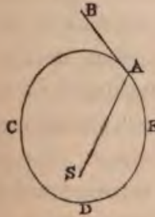


Fig. 29.

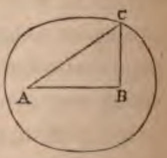


Fig. 30.

other conic section. An ellipse may be formed easily by placing two pins in a board as at A, B (Fig. 30), and carrying a string, C, with a pencil, steadily round them.

We must not forget the harmonious arrangement of the planets of the solar system, by which the stability of its movements is permanently secured. Laplace demonstrated, that whatever may be the masses of the planets, owing to their moving in orbits of small excentricity, nearly in the same plane, and all in the same direction, from east to west, their inequalities of motion are very limited; and these oscillate about a mean line, the deviation of which can never exceed a certain very small quantity. The earth's ecliptic, for instance, will never coincide with the equator, and, according to the same high authority, the extent of the variation in its inclination cannot exceed three degrees. Another provision to secure the stability of this great system of rolling worlds, is, that those planets nearest the sun have the largest excentricities and the smallest masses. The mass of Jupiter is more than 2,000 times greater than the mass of either Mercury or Mars; consequently, the gravitating force of this large planet and of the others beyond it is exerted, as a balance, against the force which is centered in the Sun. This orb holds all these huge masses chained to it, under the influence of gravitation: they would eventually fall into that orb, but for this restraining balance of power. In the accompanying diagram (Fig. 31) a portion of the Sun's circumference is shown, and the planets Mercury, Venus, Earth, Mars, Jupiter, and Saturn with its rings, in the order of their distances from the Sun, and, as nearly as possible, of their relative sizes.

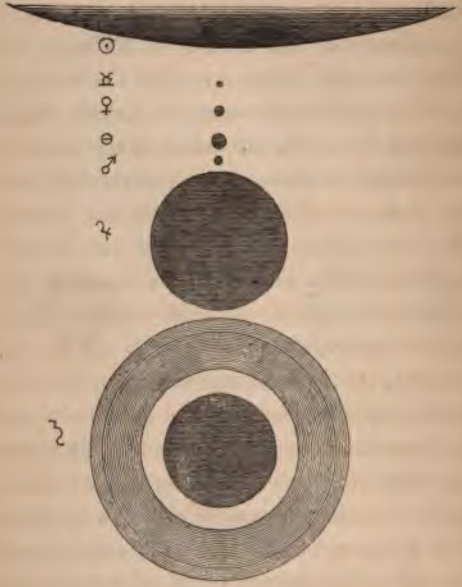


Fig. 31.

By a knowledge of this universal law, the astronomer is enabled to determine the weight of bodies on the surface of the sun and planets, and to calculate the quantity of matter contained in the sun, or any planet having satellites, and to determine the density of the matter of which they are composed. Newton, by this law, proved that the same body would weigh twenty-three times as much at the surface of the sun as it does at the surface of the earth; that the earth had a density four times greater than that of the sun; and that the planets increased in density as their distance from the centre of our system was enlarged. The recent discovery of Neptune—an honour for which the two proudest nations on the earth contend—has given the utmost degree of confirmation, were any wanting, to the universality of gravitation and the truth of the laws developed by Newton. It was observed that the planet Uranus suffered some disturbance in a certain portion of her orbit. Perturbations were observed in the line of her path, which could not be referred to the influences of any known attractive force. In the midst of this difficulty, two young men—Adams in England, and Le Verrier in France—assumed the existence of a planet beyond Uranus;—from the amount of the perturbations they calculated the position of this hypothetical mass, determined that those irregularities could be accounted for in this way, and that, if the law of gravitation was true, at a given time, near a certain point in the heavens, the disturbing planet would be found. The astronomer brought his telescope to bear upon this portion of space, and the planet Neptune, lying on the outside of our system, was revealed to him.

The intensity of gravitation is in direct relation to the mass of the attracting body. The sun is, therefore, in virtue of its enormous bulk, which is some hundred times greater than that of all the planets taken together, capable of holding within its power this vastly distant planet—Neptune—moving many hundreds of millions of miles distant from the attracting centre. Yet this great force, so universe-extending, is employed to regulate a falling rain-drop.

It was determined, in the first place by Condamine, that a lateral attraction was exerted by mountains and other large masses of matter; and Maskelyne made some very conclusive experiments on the attraction of the mountain Schehallion. This was to be inferred from the facts of mutual attraction which we have already named. If a plummet is hung from the top of a tower or the edge of a precipice, it will deviate from the true line, owing to the attraction the mass of the tower exerts on the lead. This is, of course, too slight to be observed in the ordinary way, but the fact is susceptible of proof.

As the earth rotates from east to west, each point of her surface describes an arc proportional to its distance from the axis; therefore a falling body has, from the beginning of its fall, a tendency towards the east: that is, if *a b* is is a well-ascertained perpendicular, and a body is set free to fall from *a*, the point *b*, being carried forward by the earth's rotation, the body will fall along such a line as *a c*. Experiments of this class have been made by Guglielmini, Benzenberg, Reich, and Oersted, which give a deviation to the

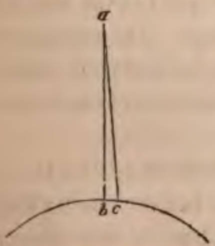


Fig. 32.

east of the true perpendicular of 3·95 French lines. These results have been confirmed by experiments in some of the deep mines of Cornwall. Beyond this, a deviation to the southward of the true perpendicular has been detected, which deviation does not admit of that easy explanation which the direction of the earth's motion enables us to give to the former.

All bodies mutually attract each other; hence, supposing a mass to be approaching the earth under the influence of the gravitating power of our planet, the falling mass is attracted by the earth, and at the same time the earth is attracted towards the descending body.

This form of attraction is shown to us in the most striking manner in the *phenomena of the tides*. The height of the surface of the sea at any given place, will be observed to be liable to periodical variations, which will be found to connect themselves with the alterations of the position of the moon relatively to that place on the earth's surface; and in some measure also to those of the sun. There are three oceanic tides to be distinguished. The first kind occurs twice a day;—the second, twice a month;—the third, twice a year. Every day, near the time of the moon's passing the meridian, the sea is elevated, and it is said to be *high water*. This elevation subsides, and it reaches its lowest point in about six hours: its point of greatest depression is called *low water*. As the moon passes the meridian below the horizon, another elevation occurs, so that we have the ebb and flow of the tide twice every day; the time becoming later each day by about 50½ minutes, which is the excess of a lunar day above a solar one,—28½ of the former being nearly equal to 29½ of the latter.

At the times of the new and full moon the tides are very sensibly affected: these are called *spring*, producing the highest and lowest water, and *neap* tides, which neither rise so high nor fall so low. The increase of elevation is more striking when the moon is in its perigee, or nearest point to the earth. The greatest elevation of the tides occurs at the time of the equinoxes; so that the waters are drawn up to their maximum tidal height when a new or full moon happens near the vernal or autumnal equinox, while the moon is nearest the earth.

These remarks have reference to the tides of the ocean: the tides of rivers and lakes are influenced by local causes which we have not now to examine. Newton shows, and the investigations of mathematicians have confirmed his views, that the tides are the result of gravitation. And we can well understand that a fluid free to move

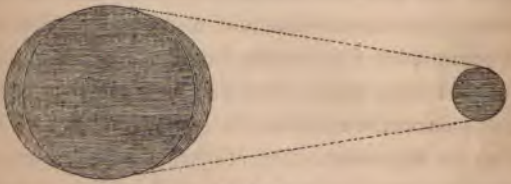


Fig. 33.

would necessarily be affected by an attractive force, which would not produce any apparent influence upon a solid mass. Supposing the earth to be a fluid sphere (Fig. 33), it would always be drawn up on that side which faced the moon, while a corresponding elevation would appear on the side most distant from her influence, and the greatest depression would be equidistant from these points.

Something like this may be regarded as the condition of the great oceanic tides. In estimating the times and heights of the tides, we have to consider the influence of the solar as well as the lunar attraction,—the latter being, however, always the most considerable; and the investigation is complicated by alterations in the relative positions of the sun, the earth, and the moon, by the ever-varying depth of the ocean, and other causes—local attraction and winds.

The atmosphere in which we move and live is affected by the attractive forces of the sun and moon, in a similar manner to the waters. The oscillations of the barometer show us the ever-varying height of the column of air; and the more complete observations of modern meteorologists are advancing rapidly towards the proof that aerial tidal waves, similar to those of the ocean, are produced in obedience to the laws of gravitating attraction.

Such are the operations of this force in producing some great phenomena of nature. We must now consider the same power in its less striking but no less important influences.

If a cannon-ball is fired from A towards B (Fig. 34), instead

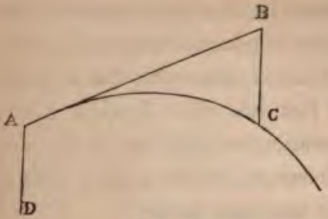


Fig. 34.

of moving along the line A B, it is, under the influence of the earth's attraction, forcibly drawn downward, and its path is along a line which is described by the parabolic curve A C; and, although it has been moving onward from the impulse it received from the explosion of the gunpowder, it occupies exactly the same time in falling to the point C, as if the ball had been allowed to drop from the hand at A, and fall to D.

Experiment has proved that a body falls through space with a constantly accelerating force; another form of illustration will render this clear. Suppose from a point A,

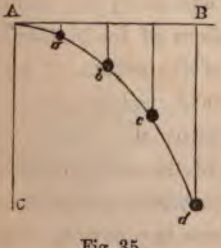


Fig. 35.

about two hundred and forty feet above the earth, a ball was projected in a perfectly horizontal line A B, instead of traversing this line it would, at the end of the first second, be found that the ball had fallen 15 feet, and be at *a*; at the end of the next second it would have passed onward, but have fallen to *b*, 60 feet below the horizontal line; and at the end of the next second it would have fallen 135 feet below the line, and be at *c*; and thus it would move forward, and reach the earth at *d*, 240 feet, in precisely the same time as it would have occupied in falling from A to C.

The velocity of falling bodies is measured experimentally by Attwood's machine; which consists of a pulley revolving round a horizontal axis fastened to the top of a vertical column about seven feet in height, Fig. 36. A cord is placed over the pulley, having equal weights at its extremities, which of course, hang in equilibrium: but any addition being placed on *a* disturbs this; and supposing the weight *b*, one ounce, is placed on *a*, the mass put in motion will be the weight and its added burden, which mass will obey the same laws as in a free fall, but with an intensity diminished by the weight of the counterpoise. If as a free body the mass fell fifteen feet in the first second, in the experiment with the machine it would only fall one foot. The weight *b* is formed as represented, that it may be arrested at any given moment by the perforated slide *c*; so that we can determine, by placing it at different heights on the graduated scale, the exact rate of the fall for every second—the time being marked by the seconds pendulum *d*.

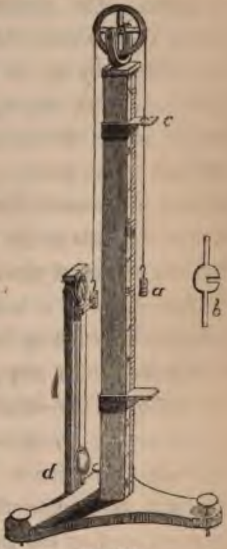


Fig. 36.

Numerous experiments have been made upon falling bodies by Galileo, Grimaldi, Dechalles, and others, in which the results have been measured by a free fall from great elevations. The spaces through which bodies fall, are always smaller than theory indicates, owing to the resistance offered by the air to its passage, which increases in accordance with the square of the velocity. Since we cannot ascend far from the earth's surface to test the decrease of the power of the force of gravitation, we may, without any sensible error, consider it uniform, and state that a body falls at the rate of rather more than sixteen feet in a second of time.

The height of a tower or the depth of a well may be determined by letting fall a stone, and noting the number of seconds which elapse before it strikes the ground or the surface of the water. Then, by squaring the number of seconds, and multiplying the product by 16½ feet—a close approximation to the truth—we have the height or the depth required, nearly; (a slight error, arising from the time required by the sound to travel from the surface of the ground or from the water to the ear, always existing, by which the calculated height or depth is uniformly made a little greater than the real.)

All bodies falling from an equal height occupy the same time in falling through a corresponding space. When we let go a feather and a lump of lead, the one floats on the air, and the other falls to the ground very rapidly; therefore this (and many other examples might be given)

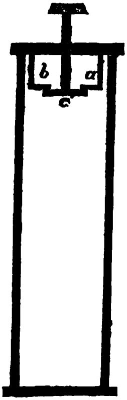


Fig. 37.

appears like a contradiction to the law. But it is not so: the feather floats because the air is heavier than it, and it cannot overcome the resistance offered. But if we place a lump of metal and a feather at the top of a cylinder exhausted of air, and liberate them at the same time, they will fall in equal periods. This interesting experiment is easily tried by the apparatus represented at Fig. 37. Attached to the cover of a tall glass cylinder, from which the air may be withdrawn by an air-pump, are two brass shelves, *a*, *b*, which move on hinges, and are kept in a horizontal position by the key *c*; on turning the key the shelves fall, and any bodies placed upon them are liberated at the same moment.

When a body moves down an inclined plane or a curve, it acquires a velocity which will carry it up again on the other side; and supposing the moving mass to be unopposed by friction, it would ascend to the same height on one side as it has descended on the other. In the *pendulum*

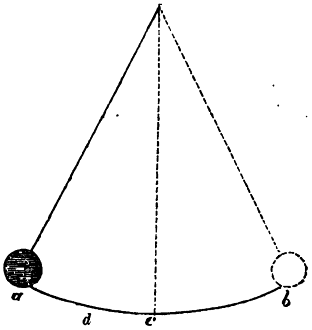


Fig. 38.

we have an example of this. The ball of a pendulum, a weight suspended from a string, is raised to *a* (Fig. 38), and set free: it falls with increasing velocity to *c*, under the influence of gravitating force, and the momentum it has acquired carries it onward to *b*. In the use of this instrument the whole movement of the ball from *a* to *b* is called an *oscillation*; the curve from *a* to *c*, or from *c* to *b*, a *semi-oscillation*. As the movements of the pendulum are strictly dependent on gravitation, it furnishes a very accurate instrument for determining the intensity of this force. An example of this will render it apparent.—

At Greenwich, a pendulum, to complete its oscillation in a second, must be 39·1393 inches in length; one to vibrate in half-seconds must measure 9·7848, or rather more than $9\frac{3}{4}$ inches. If, with the same length of pendulum, more time is required to complete the oscillation, we learn that the force which pulled the weight from *a* to *c* is lessened, or, if the oscillation is performed in less time, that it is increased. On account of the form of the earth, therefore, a pendulum must be one-fifth of an inch longer at the poles than at the equator, to vibrate seconds.

The laws of the oscillations of the pendulum should be fully understood. They are, 1st, *The duration of an oscillation is quite independent of the weight of the ball, or of its nature.* Whether we swing balls of metal, stone, wood, or wax, we shall find the oscillations will have equal durations; and whether the ball weighs a grain or many pounds it signifies not, since in a mass every atom acts by its own gravity, so every atom of that mass will oscillate in the same time as the mass. The resistance offered by the air, of which we have already spoken, must be of course removed. 2nd. *The duration of small oscillations of the same pendulum is independent of their magnitude.* If the pendulum begins its motion at *a*, the accelerating force is twice as great as when it is set free at *d*; and if we take two pendulums of equal lengths, and liberate one at *a* and another at *d* at the same time, they will simultaneously arrive at *c*. 3rd. *The durations of the oscillations of pendulums of unequal lengths, are as the square roots of the lengths of the pendulums.* While a pendulum four feet long makes one oscillation, another which is but one foot in length will make two; and if such a pendulum moves in a given time three times forwards and backwards, another measuring nine feet will make but one oscillation. Experiments made with balls tied to measured lengths of string will prove these laws. The mode in which a pendulum is applied to regulate the motions of clocks, is shown in the margin. The wheel A A is turned by a weight attached by a line to the axis *a*, but added to the pendulum is a beam *b*, having a tooth at either end: the tooth is shown holding

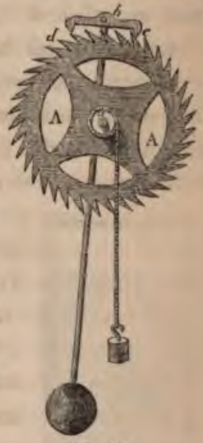


Fig. 39.

the wheel by one of its teeth at *c*; the return of the pendulum will, of course, liberate the tooth at *c*; at the end of its oscillation, the teeth will meet at *d*. The wheel moves one tooth at each oscillation,—thus the motion of the wheel is entirely regulated by that of the pendulum; this arrangement being called an *escapement*.

If we consider that all matter is *inert*—that it has no power to move itself,—and that the amount of *inertia* is as the quantity of matter, a greater force being required to move a heavy than a light body,—we shall speedily see the attraction exerted to move a mass of metal towards the earth is as much greater as the difference between its mass and that of a feather. Thus, supposing a lump of metal to equal in mass 500 grains, and a feather to equal only 5, one hundred times more force must be exerted to draw the metal to the earth than is necessary to occasion the fall of the feather. We see a balloon or a soap-bubble ascend; and a cork, or other light body, placed at the bottom of a vessel of water, rises through it and swims on the surface. This is a direct consequence of gravitation—the attraction of which, increasing with the quantity of matter, draws down the denser air and water, and these compel the lighter bodies to ascend. Supposing *a* (Fig. 40) a glass globe filled with air, and a little fluid, so that it floats exactly in the middle

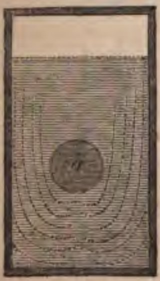


Fig. 40.

of a vessel of water,—we have an equilibrium established, and the pressure of the water on the glass is equal in all directions; but if we add a few drops of a heavier saline solution, we shall see, as it sinks and mixes with the water, that the globe *a* is forced to the top of the fluid, owing to the exertion of the attractive force of gravitation on the denser fluid compelling it to occupy the place of *a*.

Weight, then, is a property of matter produced by the attraction of the gravitation of the mass of the earth. Taking the instance of our lump of metal and feather, if we place the metal *a* at one extremity of a well-poised beam, and the feather *b* at the other, we shall find that the metal is drawn to the earth with a force exactly equal to the superiority of its mass over that of the feather. If, however, we tie on a sufficient number of feathers to produce a quantity of matter equal to that of the metal, the equilibrium is restored—the two quantities are attracted with equal force—the beam is supported in a horizontal position; we have, by a

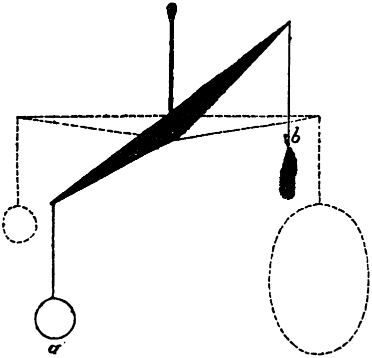


Fig. 41.

pound or an ounce of lead, determined the quantity of matter in a pound or an ounce of feathers.

As this force varies with the distance of the body to be weighed from the centre of the earth, it follows that a mass of matter weighing a pound at the earth's surface is diminished in actual weight about a 2000th part, or three grains and a half, if it is weighed a mile above that surface. A thousand pounds of matter loses two pounds of its weight if elevated four miles above the earth; and if such a mass was carried to a distance equal to that of the moon, or to be removed 240,000 miles from the earth, it would not exceed five ounces. We see it sometimes incautiously stated that the weight of a body on the surface of the sun or the moon would be so much less than on the surface of the earth. This is a very incorrect way of putting the fact: the *earth's* attraction on the mass would diminish relatively with the increased distance; but from the influence of the gravitating power of the mass of either of these other globes of matter, the weight of the body would not be determined by this gravitating force.

Weight is the sum of all the gravitating influences acting upon and in a mass of matter; or, in other words, it is the amount of pressure exercised by one body upon another. We take a mass of

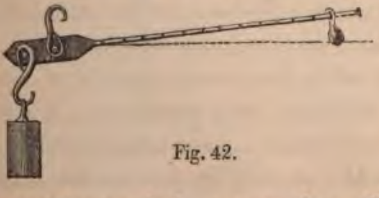


Fig. 42.

matter, in our hands and say it is heavy or light according to the force with which it presses upon them. The instruments employed for the comparison of weights are steelyards (Fig. 42) and balances. In the steelyard a single weight has different values as it is moved along the one graduated arm, which acts as a lever. In the balance—too familiar to require illustration—the two arms should be precisely equal, and equidistant from the centre of suspension; the scales being freely suspended from fixed points at the ends of the arms. Great attention is necessary in the adjustment of a balance, to ensure perfect accuracy; and where balances are required for very delicate determinations, the construction of them becomes a most refined mechanical operation. Mr. Ramsden made balances of such accuracy that, though capable of weighing ten pounds, they would turn with one ten-millionth part of the weight in the scales.

In this country our system of weights is not so well-defined as it is to be desired it should be. Two systems, Troy and Avoirdupois, are employed; the former for weighing gold, and as the apothecaries' weight, whilst the latter is employed in all trade transactions.

Troy weight, which is derived from the ancient name of London, Troy-Novant, according to the legend of Brutus and Corineus, and which has existed from the time of Edward the Confessor, has 5,760 grains to a pound of 12 ounces. Avoirdupois weight—the name being derived from *avoirs* (averia), goods or chattels, and *poids*, weight—consists of 7,000 similar grains to its pound of 16 ounces.

The relation which our measures of length and weight bear to each other will be understood by the following statement, abridged from the act settling the Imperial System.—

A pendulum which will perform its oscillation in a second from A to B at London, on a level of the sea, and freed from the resistance of the air, is taken, and the part which lies between the axis of suspension *d*, and the centre of oscillation *c*, is divided into 391,393 equal parts; of these parts, 10,000 will be an imperial inch, twelve of which make one foot, thirty-six of them one yard. One such inch (cubic) of distilled water, at 62° of Fahrenheit's thermometer, is taken and weighed: this weight is divided into 252,458 equal parts, and of these 1,000 will be a *grain*. Ten pounds, of 7,000 of those grains, of distilled water at the same temperature, will be a gallon, which gallon will contain 277 cubic inches and about one quarter of a cubic inch more.

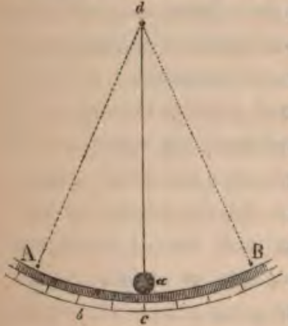


Fig. 43.

In France, the *gramme* is the legal standard; the gramme being the weight of a cubic *centimetre* of distilled water in its state of greatest density, namely eight degrees above the freezing point. The French standard of measure is the earth's meridian. The forty-millionth part of a line, forming the meridian passing through both poles, is a *metre*. This is divided into 10 *decimetres*, 100 *centi-*

metres, and 1,000 *millimetres*. Now, this cubic *centimetre* of water, 1 gramme, equals 15·44 grains troy, and one pound troy is equal to 373,202 grammes.

Specific gravity, or *specific density*, as it connects itself immediately with weight, cannot be more properly considered than in the present place, although many of the instruments employed in its determination belong especially to Hydrostatics.

Specific gravity is the relative weight of any body compared with an equal bulk of some other body; and, by common consent, distilled water is regarded as the standard of comparison. It fortunately happens that a cubic foot of pure water weighs exactly 1,000 ounces avoirdupois; hence we have an easy system of calculation, since the numbers expressing the specific gravity of any body enables us to determine the weight of a cubic foot of that body in avoirdupois ounces.

The following laws of specific gravity should be clearly comprehended.—

1. In bodies of equal magnitude the specific gravities are directly as their weight.

2. In bodies of the same specific gravities the weights will be as their magnitudes.

3. In bodies of equal weights the specific gravities are inversely as the magnitudes.

4. The weights of different bodies are, to each other, in the compound ratio of their magnitudes and specific gravities.

Archimedes appears to have studied with great care all the laws of specific gravity. If we receive the story of his observing that his body displaced an equal bulk of water when he plunged into the bath, and that from this circumstance he was led to the discovery of the means of determining, from its specific gravity, the deterioration of the gold in Hiero's crown by the introduction of base metal, we must not regard the circumstance in the light of a mere accident, since it is evident that the mind of that extraordinary man had been devoted to the subject, and was thereby fitted to receive and profit by the hint nature gave him, which no other man would have so carefully observed.

The mode adopted for ascertaining the specific gravity of solids will be easily understood upon consideration of the circumstances attending the immersion of the philosopher in his bath.

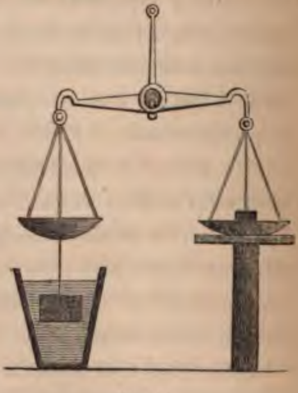


Fig. 44.

If we had ascertained the exact weight of Archimedes in the air, and weighed the water which he had occasioned to flow over the bath—that water being exactly equal to the bulk of his body,—we learn the weight of a mass of water of its size, and we have the relations of one to the other.

The mode adopted, however, for obtaining the specific gravity of a body heavier than water, is, to ascertain its weight in the air, and then, attaching it by a piece of horsehair to the bottom of a scale-pan, to place it in a vessel of distilled water, and weigh it, as shown in Fig. 44; then subtract the weight in water from the weight of the body in air, and divide the latter by the difference.

Thus a piece of metal weighs in air	4094	grains.
The weight of it in water is	4048	,,
Subtracting one from the other	46	,,

Then dividing its weight in air, 4048 grains, by the difference, 46 grains, we have the specific gravity of the metal (water being 1) given as 8; or, a cubic foot of water weighing 1,000 ounces, a cubic foot of this substance would weigh 8,000 ounces.

When the body is lighter than water, it is usual to tie it to a heavier body, whose weight in air and water is known. The pair, as united, are weighed both in air and water, and the loss of weight ascertained. As we know the weight lost by the heavy body itself in water, we can readily ascertain the differences; and by dividing the weight of the light body in air by this number, the specific gravity of it is obtained.

The specific gravity of fluids is arrived at with great readiness by obtaining a bottle capable of holding exactly

1,000 grains, and, having counterpoised this, removing the water and filling it with the fluid, the specific gravity of which we desire to know; then dividing the weight of the fluid by the weight of the water, the quotient is the number required.

The specific gravity of fluids—as, for example, spirits, which vary with the quantities of absolute alcohol and water they may contain—is conveniently ascertained by means of an aerometer or hydrometer. This instrument is said to be the invention of Archimedes. It consists of a hollow ball, with a weight below it, and a slender stem above it, which is graduated by experiment to express the specific gravity of fluids by the depth to which it sinks. The ordinary form of this instrument is represented in the adjoining woodcut; and it will be readily understood, that if it sinks in water to a certain line on the graduated limb, it would fall lower in fluids which were lighter than water, or rise above that line in those which were heavier.

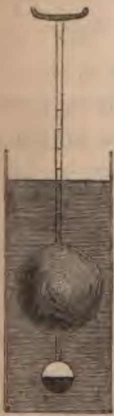


Fig. 45.

It must always be remembered, that in taking the specific gravity of any substance, the water employed must be distilled, or, at least, boiled rain-water, and maintained at a uniform temperature of 60° Fahr.; or if this cannot be done, a correction must be made for the difference of temperature. Water expands with every increase of temperature above 40°, and consequently its specific gravity diminishes as the temperature increases.[*]

To ascertain the true specific gravity of any body weighed in water, we have only, therefore, to multiply the specific gravity as found by that of the water at the temperature at which the experiment was made. A Table of specific gravities of the metals, stones, woods, fluids, and air, will be found at the end of this volume.

Centre of Gravity.—The stability of bodies depends upon the adjustment of their centre of gravity. The centre of gravity is nothing more than the central point of parallel or equal forces. Thus, the centre of gravity of a sphere is the centre of the sphere itself; but this is not the case in any irregularly-formed body, as may be readily proved by suspending such from two points by a string, when it will be found to arrange itself in such a manner that the continuation of the line of the string in

---

[*] The following table shows the variation for ten degrees below and above the mean point 60°, when water is sp. gr. 1·000.

TEMP.	SP. GR.	TEMP.	SP. GR.
50	1·00068	61	·99991
51	1·00063	62	·99981
52	1·00057	63	·99971
53	1·00051	64	·99961
54	1·00045	65	·99950
55	1·00038	66	·99940
56	1·00031	67	·99929
57	1·00024	68	·99918
58	1·00016	69	·99906
59	1·0008	70	·99894
60	1·00000		

the two experiments Fig. 46, or the point where these two lines intersect, will mark its centre of gravity.

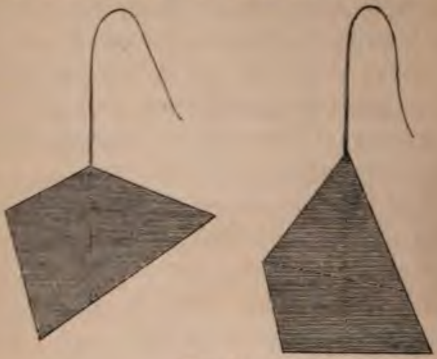


Fig. 46.

A wall stands secure as long as the perpendicular drawn through its centre of gravity falls within its base. The leaning towers, of Pisa 315 feet high, with an inclination from the perpendicular of 12·4 feet, and of Bologna, the height of which is 134 feet, and which has an inclination of nine feet, celebrated examples of this. instance, the line in the ining diagram, from points *b*, falls within the base, it stands securely; but

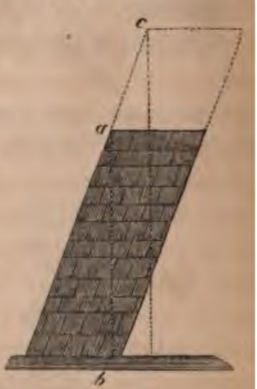


Fig. 47.

supposing it to represent a section of a leaning wall, and that an attempt was made to carry it a little higher to *c*, the perpendicular line from *c* would then fall without the base, and the structure could no longer support itself. An oval body—an egg, for example—placed on a plane, maintains a stable equilibrium while it rests on its side; but it is in a very tottering condition when it stands on the extremity of its longer axis;—this is owing to the difficulty of placing it so that the line cutting the centre of gravity may always fall through the base.

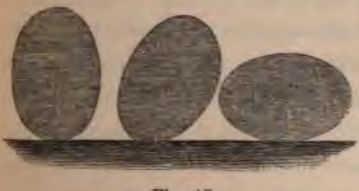


Fig. 48.

In every movement of the body a man adjusts himself, by instinctive habit, to the necessary conditions. He attempts to rise from a chair;—he draws his feet inward, that he may bring the support of the body into the vertical line passing through the centre of gravity; thus to produce that instability of equilibrium which is necessary to the beginning of motion. If we suddenly check ourselves, having made the attempt to rise from our seat, we shall find that we have by no means placed ourselves in an easy position. If a man carries a weight in his right hand, he bends his body towards the left. If he has a load placed on his back, he leans forward;—if he stood perfectly upright, the force drawing him backwards would be excessively fatiguing; if, on the contrary, he has a weight placed in his arms, he bends his body backward, and thus adjusts himself to the shifting of the line of equilibrium, which we call the centre of gravity. In fact, we may regard this kind of adjustment as resembling the conditions of the steelyard;—additional weight being added at one end, we move the constant weight further from the fulcrum, and thus equalize the amount of muscular force and gravitating power. If we place a man with his back and heels against a wall, and desire him to stoop forward and pick up a piece of coin placed at his feet, he will find himself unable to do so, or, if he perseveres in his attempt to bend the body, he will fall forward: were he allowed to throw out his leg, and thus secure a broader base, he would experience no difficulty; then, as in the examples we have already given, the vertical line cutting the centre of gravity would still fall within the base. This point has also been called the *centre of inertia*, which term, thus applied, requires explanation. It has already been explained that matter is *inert*; no mass of matter can move itself, or, if in motion, can suspend its progress. An equestrian at Astley's is carried round the arena by his steed, his body acquiring precisely the same speed as that of the horse; consequently, in performing the feat of leaping through a drum, he has only to spring sufficiently high, and he is carried through the drum, in virtue of his inertia, at the same speed as the horse passes under it, and he descends again exactly on the saddle. If he added muscular force to throw himself forward, this, added to his acquired velocity, would occasion him to fall on the head or neck of the horse, and consequently endanger him. We will suppose ourselves standing upright on the deck of a steamboat, going through the water at the rate of ten miles an hour: our bodies are moved at that rate, and if she was suddenly stopped, by a rock or any interruption to her speed, we should all be thrown down with dangerous violence, since we have acquired a motion which an *inert* mass cannot control, and consequently cannot suspend; for every moveable body—chairs, tables, and the like—will continue the motion they have thus acquired, after the speed of the vessel has been checked, and they would receive a blow, as violent as that which would be given to them supposing those things to be hurled forward at the rate of ten miles an hour.

If we are standing in a carriage at rest, and the horses suddenly start off, we fall backward, because the centre of inertia, or of gravity, is, when, at rest, marked by a certain line proceeding through it to the mass of the earth; and this line of force, not admitting of any instantaneous change of direction, holds us along that line, and the carriage being dragged onward by the horses suddenly, we must fall, in obedience to this law.

In looking through the cosmical arrangements, it will be soon discovered that a great number of remarkable phenomena are directly dependent upon the exertion of gravitating force, which acts by modifying the operation of other forces, or by directly influencing the result.

The stability of the ocean, for example, is secured, from the circumstance that the mean specific gravity of the earth appears to be about *five* times that of water. On this point Laplace says, "In virtue of gravity, the most dense of the strata of the earth are those nearest to the centre, and thus the mean density exceeds that of the waters which cover it; which suffices to secure the stability of the equilibrium of the seas, and to put a bridle upon the fury of the waves." It therefore appears necessary that the strata of the earth should increase in density with its depth below the surface; but owing to superficial disturbances this is not found to be strictly the case within the limits of depth below the level of the ocean —about 2,000 feet—to which man has reached.

By the mass of the earth—that is, by the exertion of gravity—is regulated the ascent of the sap in vegetables, and also the circulation of fluids in the animal economy.

Under the influence of the capillary and epipolic forces, which have already been mentioned, the roots absorb fluids from the soil, and these fluids are raised by an enormous power to the tops of the highest trees and the extreme ends of every branch. It has been proved by Hales, that a vine, at the season when the sap is ascending, has the power of raising the fluid in a glass tube to the height of twenty-one feet above an amputated branch.

The weight of this column, amounting to several pounds on every square inch, is supported by the operation of certain vital forces, which are adjusted to be in excess to the gravitating power; and any alteration in the amount of this force would, of course, occasion such disturbances in these processes, as would be destructive to organic life. The mass of the earth also regulates the muscular movements of animals. If the force of gravity were increased by any alteration of the earth's density, the bird would no longer soar gracefully upon the air, the fleetest animals would become sluggish in their movements, and even man, unable to support his stately position, and "gaze upon heaven with a forehead erect," would be compelled to crawl slowly over the surface of his world; which would, from that alteration in its atmosphere, which must of necessity follow any disturbance of the gravitating power, become to him a place of misery, and the labour of existence would be rendered insufferable. However, so nicely are all these powers—which may indeed be regarded, with some others, as being antagonistic to each other—balanced, that harmony and beauty are found throughout nature: and the earth is established, under the guiding operation of the universal power of gravitation, as the abode of animals formed to enjoy the gladness of life or to rejoice in the blessings of a heaven-born intelligence.

Gravitation has been spoken of as a universal power. It is exhibited to us in the phenomena of the attraction of bodies according to their mass. Two bodies are pulling one towards the other, the force increasing as the distance between them diminishes. Can we understand what the nature of this force is? We have been told, it is a property of matter, and some have been thus satisfied with a definition signifying nothing: but the result of serious thought must be a declaration that we know not what gravitation is; and a close examination of its phenomena appears to prove the existence of another physical power, of a more exalted character than gravitation, by which its influences are controlled. At all events, the indications of science tend towards such an inference. We find Cohesion operating as an aggregating power, as a capillary and epipolic force, regulated by the all-penetrating agency of Gravitation; and in the consideration of the mysteries of the molecular constitution of masses, we cannot avoid the indications of other great principles, or, at all events, of one other power, to which the known physical forces are bound in obedience, but which is still but the material minister acting according to the will of the Great Omnipotent, in maintaining the harmonious laws of the universe.

CHAPTER II.

THE GENERAL LAWS OF MOTION.

THE most perfect exemplification of the primary law of motion, is the rotation of the earth itself. The law, as expressed by Newton, is, *that a body at rest continues at rest, and that a body in motion goes on moving without altering its velocity or direction,* unless compelled by some extraneous forces to change it. A ball discharged from a rifle does not move for ever, howsoever great may have been the force by which it was impelled. Here we have the resistance of the air (*friction*) and the power of gravitation, acting extraneously to reduce the force of motion, and bring the body to a state of rest. All motion is the result of some mode of force; and in the example of the earth's rotation, although we cannot clearly define all the causes at work, there can be no doubt but its uniformity is due to the constant expenditure of some external force. Laplace's calculations show that it is impossible that a difference of one-hundredth of a second can have taken place in the length of the day since the most remote antiquity. Now, although the earth's motion has been usually referred to the *first law*, this wonderful regularity appears to indicate the operation also of the second and third laws of motion. These are—*When a force acts on a body in motion, it produces the same effect as if the same force acted on a body at rest*;—and, *When a force of the nature of pressure produces motion, the velocity produced is proportional to the force, other things being equal.*

Upon these three laws (which, indeed, the French reduce to two—the law of inertia and the law that force and velocity are proportional) depend the phenomena of all dynamical effects. Since the whole science of Mechanics depends on the laws of motion, it becomes most important to examine the fundamental principles upon which they are based. This examination will require some accurate attention; but the illustrations are chosen from the most familiar objects, and the whole subject is relieved as much as possible from metaphysical subtleties, which have, perhaps unavoidably, been introduced into the study of mechanical philosophy.

Motion has been defined to be the change of distance in a right line between two points. Thus *a* and *b* have, both

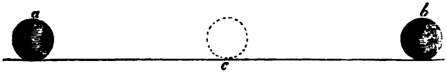


Fig. 49.

being at rest, a certain amount of space between them: a force is applied to *a*, it moves to *c*,—a change of distance has taken place.

Motion may be either relative or absolute, but in most cases close examination will prove that absolute motion is merely imaginary. A ball, for example, is propelled along the earth's surface from *a* to *b*, we regard the two points *a* and *b* as quiescent, and hence this is a case of absolute motion; but every point of the earth's surface is constantly moving in various directions, consequently, while the ball has been passing from *a* to *b*, the points *a* and *b* have changed, and the motion of the ball *a* is a relative motion, the alteration being shown by the deviation of the lines *c c* and *d d*, in relation to a point in space, A.

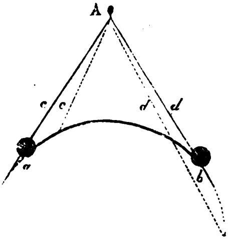


Fig. 50.

When we say a body is at rest, we (correctly enough, as an expression of all that our unaided senses can teach us) compare the body with other points, and relative to these its rest is absolute. For example, a cannon-ball on the deck of a ship sailing down the channel, is at rest as compared with other bodies on the same deck—an anchor at the bows and the steering-wheel at the stern; but it is, equally with the ship itself, in motion as compared with two points on the surface of the globe, say Beachy Head and the Lizard; and these points are themselves in motion by the earth's rotation and its movement in its orbit around the sun; and, again, the sun and its system of planetary worlds are all moving at a rapid rate around a far distant centre. The result thus produced is called the *composition of motion*, or, the joint effect of more than one motion existing at the same time. If several points move in parallel lines over equal spaces in equal times, they are at rest with regard to each other, as in the example of the ball, the anchor, and the steering-wheel.

Rectilinear motion is the movement of points in parallel lines. Thus a T square being moved along the straight edge of a drawing-board, its surface is in rectilinear motion, relative to the board.

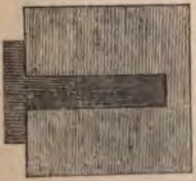


Fig. 51.

The result of two motions is well shown in the case of a carriage travelling over a perfectly straight road. The carriage moves in parallel lines, *a b* (Fig. 52), with the road, but the rotatory motion of any point of the wheels about the centre, at the same time as it is moved onward, produces a curve called the cycloid, *c d e*, and a *trochoid*, *f g h*.

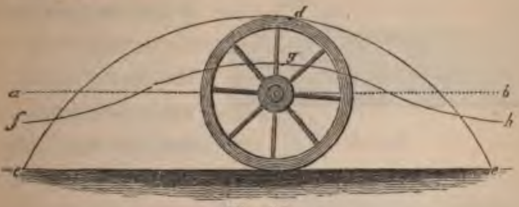


Fig. 52.

In the great work of Newton, the 'Principia,' the first corollary is, "*a body describes the diagonal of a parallelogram by two forces acting conjointly, in the same time in which it would describe its sides by the same forces acting separately*;" that is, if we have two lines, *a x* and *a y*, representing the directions and velocities of two separate motions and one force moves the point *a* to *b* in a second, while the other moves it from *a* to *c* in the same time, if both forces act simultaneously upon the point *a*, then *d* will be the place of the moving body at the end of any given time. This principle, known under the name of the *parallelogram of forces*, involves the important doctrine of the *resolution of motion*. Two rapid motions opposing each other are resolved into a slower motion, and rest may result from two equal and contrary motions.

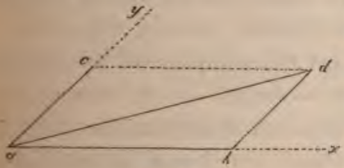


Fig. 53.

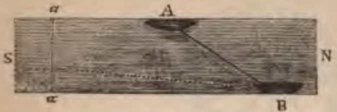


Fig. 54.

In illustration, let us place a boat, B, upon a river, which is running towards S, when the wind is blowing towards the point N: supposing that the stream would carry the boat A to the line *a a* in five minutes, but that the wind offers a resistance equal to one-half the force of the current, the boat will move by a diagonal line, and only arrive at point *b* in that time. If the force of the stream and the wind are equal, the boat will remain at rest, or in a state of equilibrium. A balloon, ascending by reason of its being lighter than the air, may be brought to a state of equilibrium by the equal influences of gravity and atmospheric resistance. A ship at anchor is held by her cable and anchor in one direction, while the tide is impelling her into another; but unless the force of the latter is greater than the power—strength—of the former, and breaks it, she remains in a state of equilibrium.

If we have three forces, and if each be equal, and opposed to the resultant of the other two, we produce statical equilibrium. Thus over two pulleys (Fig. 55), fixed to vertical rods, we place a thread, and hang to the end of each a weight, say of two ounces, *a*, *b*,—we have thus two forces acting equally, and the string will be drawn tightly across, and the weights will remain in equilibrium; but if we hang a third weight, of two ounces, at *c*, the weights will be drawn up to *e e*; but a

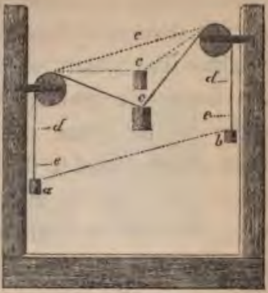


Fig. 55.

weight of four ounces will bring the point *c* lower still, and the weights to *d d*; and we have three forces acting upon the points *c c c*, in different directions, producing an equilibrium of forces in any definite position of the threads, which may be examined, by causing the pulleys to slide upon their uprights, or the vertical rods along their base.

The importance of a clear perception of the parallelogram of forces will be evident when we reflect that the laws of equilibrium in all machines are derived from it.

MECHANICAL POWERS.

The Inclined Plane, the earliest plan adopted by man to effect the decomposition of forces, must now be described. If upon the plane *c d*, forming an angle *x*, we place a weight *a*, the centre of gravity of the body is no longer at right

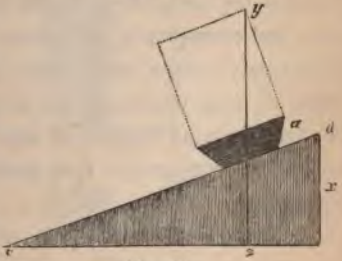


Fig. 56.

angles to the plane, but along the line $y z$, and consequently it has not to support the full pressure of the weight. The gravity of the body is decomposed into two forces, one drawing it to the earth, acting at right angles to the plane and causing the pressure, the other acting parallel to the inclined plane, and forcing the weight down it. In lifting a body vertically from the earth, we have to overcome the full force of gravity, acting directly on it; but by rolling it up an *inclined plane* we are relieved from a large proportion of this force, and thus are enabled to move great weights to a considerable height with comparative facility.

The inclined plane is of constant practical application amongst men, and it appears to have been so from the earliest ages. An ignorant man might project a road over the summit of a mountain: now, beyond the force necessary to overcome the friction in drawing a heavy load up this steep incline, he must add additional force to overcome the gravity acting parallel with the inclined plane of the road, which rapidly increases with its steepness, and consequently an immense expenditure of power is necessary to draw heavy loads up such an ascent. An informed man would see the advantage of making the road wind around the hill, by which he would be able to move, with comparative ease, heavier bodies to the same elevation.

The Screw is an inclined plane winding round a cylinder, as will be apparent if we take a rectangular piece of paper, whose length is equal to the circumference of a glass rod, and wind it around in such a manner that the horizontal side of the paper shall form the periphery, *a b*, of the base of the cylinder, the hypothenuse, as the line *a c* is termed, will wind around it in a uniformly ascending line, which line marks what is called the thread of the screw. If a triangle is continued along the thread of the screw, we have a triangular thread, A (Fig. 58). If a parallelogram is continued in a similar manner around the cylinder, we produce a flat-threaded screw, B. It need scarcely be explained that by this simple form alone little mechanical advantage is gained. If we force a screw into a piece of wood,

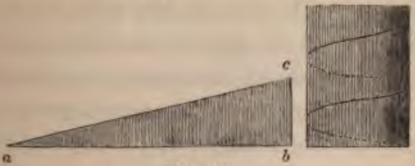


Fig. 57.

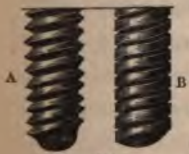


Fig. 58.

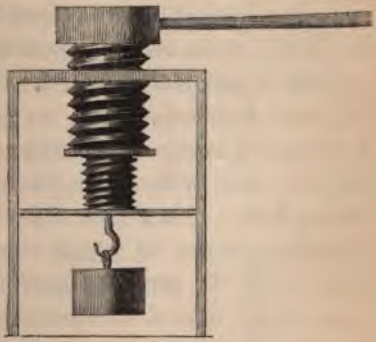


Fig. 59.

we shall find, upon removing it, that we have cut a hollow spiral, exactly fitting the projecting threads. Such is the arrangement necessary when we employ the screw to lift heavy weights, or to press forcibly upon any body. In either case it will be found upon examination that we have indeed one inclined plane moving upon another, but, in order to avail ourselves of the advantages of the screw, we employ the additional power of the lever, which will immediately be described (Fig. 59).

Fig. 60.

When two inclined planes are placed with their bases together, we have a triangular prism called a *Wedge*, which is sometimes employed to lift enormous weights to small elevations. The largest ships in the British navy are thus lifted, preparatory to launching, by driving a great number of wedges at the same time under their keels; but this simple mechanical power is more commonly employed for cleaving wood. The power of the wedge increases as its width or back diminishes. A very important application of the wedge, or rather of a combination of wedges, has been made by Mr. R. W. Fox, in blasting rocks. A round piece of wood is divided, as shown, Fig. 60, into three parts, *a*, *b*, *c*: the largest wedge, *b*, is to be placed upon the powder in the hole of the rock, and the two others,

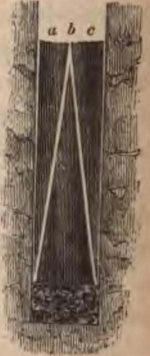


Fig. 61.

a, *c*, are dropped into their places; a small hole runs through them to convey the fuse to the bottom, which, being lighted, communicates the fire, and the explosion takes place. The wedge *b* is driven with enormous force upon the wedges *a*, *c*, which resist it, and since it becomes powerfully jammed, a greater lateral strain is exerted than by any other process, and a larger quantity of rock rended by the explosion. Cutting instruments, needles, &c., are familiar examples of the wedge.

The Pulley consists, in its most simple form, of a thin disc, hollowed out on its edges, and turning on its axis, which passes through its centre at right angles to its plane *a b*. No increase of power is gained by this arrangement, but it is often a convenient mode of applying force;—it will be readily seen that to move the weight *b* at one end of the string, passing over the pulley, a greater weight must be applied at *a*. However, if we fasten one end of our cord to a beam A, and pass it under the groove in a moveable pulley *a*, to which the weight we desire to raise is attached, and then carry it over the fixed pulley *b*, we may lift a weight of one hundred pounds, by the application of a force equal to fifty pounds. To understand this, we must remember that the

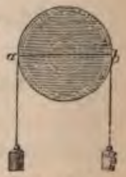


Fig. 62.

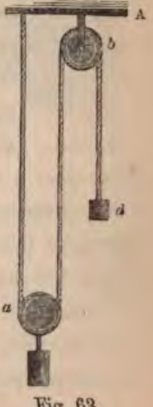


Fig. 63.

weight is supported equally by the beam and the power applied at *d*; but the string at *d* must move through two inches to raise the weight at *a* through one inch. Pulleys are usually compounded into a system containing two or more single pulleys, called *blocks*, and these frequently again combined in a compound system of fixed and moveable blocks, as is represented in the accompanying section.

If the line from the fixed point is traced, it will be seen to run under the moveable pulley *a*, over the fixed pulley *b*, under *c*, over *d*, then under the larger moveable pulley *e*, and passing over the fixed pulley *f*, it hangs loosely at *p*. Here we have six lines to support the weight B, and every line acting with a force equal to one-sixth of the weight; that is, if the weight is 120 pounds, each line supports twenty pounds of it, and therefore twenty pounds hung at *p* would equipoise the weight B. Supposing a man exerting a power of three hundred pounds, pulling at a string over a fixed pulley, as Fig. 62, could raise a mass of stone, six feet high, in a minute; a child, exerting a power of only fifty pounds upon the compound pulley, Fig. 64, would raise it to the same height, but he would require six minutes to perform the task. It cannot be too forcibly impressed upon students, that, in all mechanical arrangements, whenever we gain power we lose time;—the neglect or ignorance of

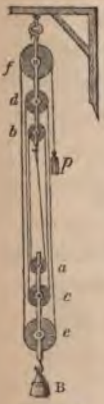


Fig. 64.

this fact has frequently led to great waste of both valuable time and hard-earned money. *No power can be produced without an expenditure of force; and as we multiply the means of applying that force, we regularly diminish the rapidity of its action.* The dreams of producing perpetual motion have arisen from neglecting these never-varying laws;—it amounts to a positive impossibility that we can ever obtain a self-moving, self-supporting power. Electricity has been regarded as the most promising of the agencies to produce this desiderated wonder, but it will be shown, when we come to a consideration of this power, that it never can be produced without some form of matter changing its condition.

The Lever has been already to some extent illustrated in the balance. It is a straight inflexible rod, turning round upon a fixed point. As a theoretical illustration of this mechanical power, let us return to our fixed pulley, but, instead of pulling the weight by the string over in the line *a b*, let us suppose we produce an elongation by an arm in the direction of the radius, as *c d*: it will be apparent that we must obtain a means of applying an increased power. A steelyard represents

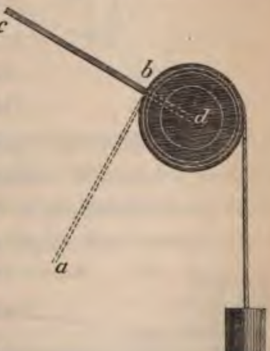


Fig. 65.

in practice the action of the lever; the small weight in Fig. 42 representing larger forces as its distance from the fulcrum, the point of suspension, increases. In a lever, like the steelyard, with unequal arms, it will be obvious, on referring to the diagram, Fig. 66, that the rate at which its two extremities move is very different. A B represents a lever moving on its fulcrum C. If a weight is placed at D, and the lever brought under it to raise it to E, the one end describes the arc D B E, while the other must move through the arc A F G; consequently a small weight moving through a larger space, with an increased velocity, acquires a degree of momentum sufficient to overcome a much greater resistance at the shorter end of the lever.

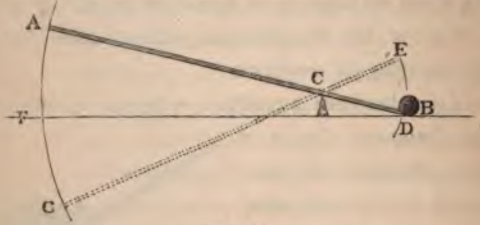


Fig. 66.

The figure in the margin (Fig. 67) represents a lever of the *first class*, having the fulcrum *a* at some point between the power applied *b*, and the resistance *c*: the poker resting on the bar of the grate is an example.

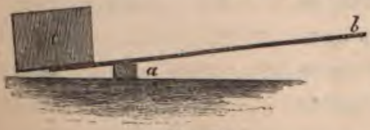


Fig. 67.

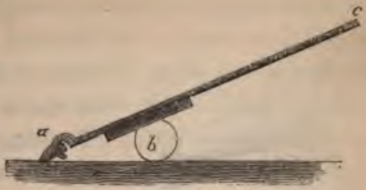


Fig. 68.

A lever of the *second class* is one which has the fulcrum at one end, *a*, the resistance at an intermediate point, *b*, the power being applied at *c*. Cork- or lemon-squeezers are examples of this form; and in rowing a boat we have an illustration.

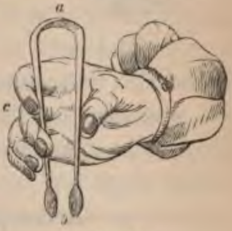


Fig. 69.

A lever of the *third class* is one in which the power is applied between the fulcrum and the resistance. A sugar-tongs well represents this form—the fulcrum being at *a*, the resistance a piece of sugar to be lifted at *b*, the power, the fingers, applied at *c*.

Fig. 70.

The wheel and axle consist of the lever applied in a modified form, by which great mechanical advantage is gained, as will be very apparent upon examination. The wheel is a series of levers, the spokes, being each one fixed on the axle. If the axle be elongated, and the resistance to be overcome be placed upon this elongation, we have the windlass. In this the weight W corresponds to the force applied at A, in an inverse ratio to the length of the arms of the lever *a*. For example, if the radius *a d* of the wheel is four times greater than the radius of the axle *b c*, we equipoise a weight by a force one-fourth of its power. If the stone W weighs 400lbs. a force equal to 100lbs. applied at A will sustain it in equilibrium. The single arm, or ordinary handle, of the capstan is to be regarded as one of the spokes of a wheel, and its power is increased with its length.

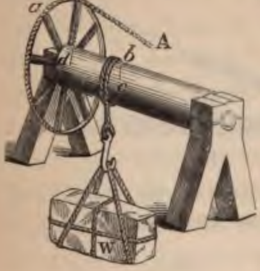


Fig. 71.

FRICTION.—In the operation of these mechanical powers we detect constantly the interfering agency of Friction. This is, obviously, nothing more than the exercise of Cohesion and Gravitation, and, as an illustration of its force, let us attach a stone to a string. To lift it from the ground a certain amount of force is necessary, but if we attempt to draw it along the surface we shall find that the resistance is considerably increased. A horse will draw one ton beside the cart, which may be half a ton more, upon a common road; but if the cart and load is placed upon well-laid and smooth iron rails, the one horse is enabled to draw from eight to ten tons. This great difference arises from the circumstance that the friction of the rough road is infinitely greater than that of the iron rails. In the latter case the rubbing is much less than in the former. If a certain force be applied to a body, to propel it along the rough surface of a common road, the moving body soon comes to rest; if it is sent along the frozen surface of a river, the friction of the ice being much less than that of the ground, the body will move for a longer time, but even on ice it eventually comes to rest, owing to the friction which still exists. In the movement of railway trains the friction of the air becomes a considerable impediment to the acceleration of their speed, the atmospheric resistance increasing with the velocity at which the engine and its train of carriages moves.

This important condition serves to ensure the stability of things on the surface of the earth; and to the *holding* force thus exerted between all surfaces, is due the firmness of the walls of a building. In every movement of man *friction* aids him. In walking or running, pulling or pushing, it assists. The foot is sustained firmly on the ground by friction;—lessen this, as when standing on smooth ice, and how difficult is it to walk or run. The hand holds the rope or the pole firmly through friction, and if we grease them, to reduce this holding power, how small is the force we can employ.

Wherever matter exists we have friction; therefore every body upon the surface of the earth soon comes to rest, unless there is a constant renewal of the force by which it has been moved. This friction, it must be repeated, is the exercise of a sort of combined influence—a modified condition of gravitation and cohesion. As bodies, from their attenuation, exhibit smaller degrees of gravitating force, the friction they exert rapidly lessens, until, eventually, the condition of matter becomes so exceedingly subtile that the rule of friction appears suspended. The ether, which is supposed to pervade all space, must be in this condition, since no retardation or interruption of the motions of "the stars in their courses" has occurred during the long periods of ages which have elapsed since the Patriarchal shepherds first watched them from the hills of Chaldæa.

Having now described the more important principles of motion,—the modes of availing ourselves of increased mechanical force,—and the counteracting tendencies which constantly act to reduce moving matter to a state of rest,—it is necessary to consider, briefly, some forms of motion which are presented in the great phenomena of Nature. It has been already stated, when considering the influence of the cohesive force, that any body made to revolve in a circle had a constant tendency to fly off from the centre of motion in a right line corresponding to a tangent of the circle. A stone in a sling A B is swung rapidly around the head; it forms, as long it is held at A, a circle, but the increasing tendency of the stone to fly off at a right line is felt as the

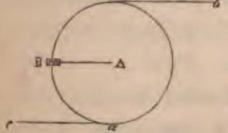


Fig. 72.

velocity is increased, and if at any moment it is set free, it flies off along some right line, as *a b* or *a c*. This is termed the *centrifugal* or centre-flying force, and any power compelling it towards the centre is called a *centripetal* or centre-seeking force. The grandest operation of these conditions of motion, is to be discovered in the arrangement of our solar system, in which a number of worlds are moving around a centre—the sun—at immense velocities, having a tendency to fly off into space by the centrifugal force, while they are restrained within exactly determined limits by the exercise of the centripetal power of gravitation;—an impulsive force is exactly balanced against a statical power, and a system of harmony is the result.

There appears to be a constant tendency to this kind of motion in moving bodies free to turn upon their axes. The earth moving upon its axis as it flies along its orbit, a ball projected from a cannon, a stone flung from the hand, all exhibit this motion, which may be prettily illustrated by placing a watch-glass upon a plate of glass, moistened sufficiently to ensure slight cohesion, and fixed at any angle: as it begins to move towards the bottom of the inclined plane, it will exhibit a revolving motion, which uniformly increases with the acceleration of its downward movement. Upon careful

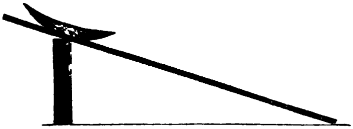


Fig. 73.

reflection, it will be seen that this phenomenon is due to the tendency of all disturbances to move from the centre to the circumference of the mass, and to the restraining influence of the cohesive and gravitating forces.

It is correctly asserted, that if the force applied to move a body is exerted on the centre of gravity of the mass, it will move forward in virtue of that force without any rotatory motion;—that the earth, being a body revolving upon its own axis, at the same time as it travels through space, must, if its motion is due to a single impulse, have received this primary force upon a point at least twenty-five miles from its true centre. A perfectly spherical shot projected from a cannon, where the explosive force is exerted on one hemisphere only, is driven round with enormous velocity in its flight, in obedience to this law. In the example of moving bodies passing through air—as they are seldom spherical—the force is always exerted on some point excentric to their centre of gravity, and they will be found to revolve round their shortest axis.

A grand exhibition of a centripetal force is exhibited in the great storms of the tropics, and, indeed, but on a more limited scale, in those tempests which occasionally disturb our more temperate region of the globe. With the aid of the annexed diagram these remarkable conditions will be rendered intelligible. The dotted line representing the true north and south, the hurricane, as is the case with American storms, is supposed to move along the thick line S.W. toward N.E.; and, at the same time as the immense mass of air is rushing onward along that line, it acquires a tendency to revolve upon its axis A with great velocity; and from the elevation of temperature at this point of greatest force, the air is rapidly rarified and flows up through that centre of the column as through an inverted funnel, the winds rushing in on every side of the circle. It has frequently been observed that vessels have been wrecked by the influence of the same storm on different sides of an island by winds blowing from opposite directions, as shown by the curved lines. If the great mass of air was stationary, the winds would all blow to a central point and up through that point; but as it is moving rapidly onward, they blow towards a point moving forward—or a central line. The dark arrows represent the direction of rotation in the storms of the northern hemisphere, and the dotted arrows the reverse line of rotation which occurs in the southern hemisphere, where the main direction of the *typhoon*, or *cyclone*, as these revolving storms are called, is from S.E. to the N.W. The following statement of one of these hurricanes, as it actually occurred, will show clearly the conditions which prevail. A ship received the wind with much violence from the S.E.: the force of it rapidly increased, the barometer fell quickly and

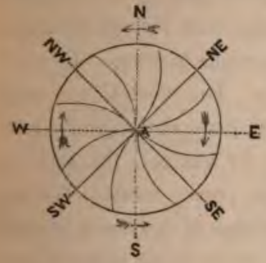


Fig. 74.

considerably until the centre of the storm reached her. The fury of the winds was hushed, and a calm of half-an-hour's duration ensued, arising from the establishment of an equilibrium of forces, the winds blowing with equal intensity inward from all sides. The wind then sprang up with increased violence, but from the opposite N.W. direction, and, after enduring for a period, the force of the wind abated, and the storm passed away. The advantages resulting from a knowledge of this *law of storms*, have been exceedingly great, as, by attending to certain indications, the mariner is enabled to ascertain his position relative to the centre of the storm, and to adopt the course which will most readily bear him beyond its influence.

The tendency of all matter, whether solid or fluid, to assume when disturbed a series of alternating movements, known by the terms *vibrations*, *undulations*, *waves*, or *oscillations*, might have claimed our attention in this chapter; but it is thought advisable, for the purpose of avoiding repetition, to reserve the consideration of these important forms of motion, until the laws of the propagation of motion in fluid bodies, and the phenomena of sound, light, and heat, come to be considered.

Before this portion of our subject is closed, it becomes, however, necessary to examine an hypothesis, which is sanctioned by the authority of some of the most talented philosophers of the present age. In explaining the phenomena which attend the production and transmission of sound, the development and the propagation of light and heat, the passage of electricity, and the varying modes of chemical affinity, they have stated that all those forms of force could be referred to motion, and that their development depended upon the character of the motion in action. Thus, a metal is acted upon by an acid, and during the *chemical* action *electricity* is developed, and under a suitable arrangement this is rendered evident by the exhibition of *heat* and *light.*—In this example it is contended that we have one form of motion producing chemical affinity, —this form of force is changed, by condition, into another, electricity,—and this again into others, heat and light.

The view entertained is, that matter, being set in vibration, gives rise, according to the order of its vibrations or undulations, to sound, light, heat, electricity, or chemical action,—that they are all, indeed, *modes of motion.* A metal bar is struck, it vibrates with much rapidity, and a ringing sound results. Here, we know that a vibratory disturbance has been commenced in the bar, that this has been communicated to the surrounding air, and that the waves beating upon the ear occasion a corresponding vibration along the auditory nerve, and the sensation of sound is produced. Reasoning by analogy, it has been inferred that light results from the vibration of some subtile principle affecting the eye; and so of the other phenomena. It has ever appeared to me that the idea of supposing motion to produce force is opposed to all experience, and contrary to the deductions which must be drawn from the evidences of sense, by which, notwithstanding their imperfections, we must be guided. It has already been shown that *force* is, in all cases, necessary to produce *motion*, and that the latter bears an exact relation to the former. No form of matter can move without the application of *a force*, and as soon as the power applied is expended the body comes to rest.

The motions of the earth and planets, and of the solar system itself, are the results of the exertion of *a force* which is dimly evident to us, and which is constantly maintained. Gravitation, we have shown, tends to the production of *motion*, but we cannot conceive motion producing gravitation. Motion must always be regarded as the result of a power applied. Motion is an *effect*, and can never strictly stand in the relation of a *cause*; its secondary influences being, still results, all of them strictly determinable from the primitive *force*, whatever it may have been.

By no strictly logical deduction can we arrive at the idea of motion *producing* either light, heat, electricity, or chemical affinity. But each of these *forces*, or agencies, are, except when they are held in statical equilibrium, constantly producing motion. The error, as it appears to me, has arisen from regarding sound as a phenomenon analogous to light. In one case we can follow all the links of the chain, from the body *moved*,—set in vibration by a *force*,—through the medium *vibrated*, up to the nerves of the ear receiving the aerial tremors or pulsations. In the other instance, even those receiving this theory are driven to suppose that there is a peculiar subtile medium, called *Ether*, which produces by its pulsations the manifestations of these great natural agents to which the theory is supposed to apply. But, even supposing we may, by the advances of science, prove the existence of this hypothetical Ether, we have still to seek for *a force* superior to and beyond it, before it can be moved. When we come to consider the laws of these great physical agencies, it will be shown to what extent the evidences of experimental examination support the idea, that variations of motion will give different forms to these subtile elements. It is, however, most important again to impress the fact, that motion cannot produce *a force*, and that *a force* must be exerted to produce MOTION.

CHAPTER III.

LAWS OF SLIGHTLY ELASTIC FLUIDS.

Fluids at Rest.—*Hydrostatics* (from ὑδωρ, *water*, and στατικη, *laws of bodies at rest*). Flowing over the solid surface of this planet, we have a most extraordinary liquid body. It is presented to us in the remarkable features of a vast ocean of never-resting water, which is, under the influence of solar heat, vaporizing, thus charging the atmosphere with moisture, which, passing over the land, is condensed by the hills, to flow in all the varied beauty of torrent and stream, or to gather into the no less important accumulations of the lake.

The largest portion of the surface of the earth is occupied by water. In the northern hemisphere it has been calculated that the proportion of land to water is as 419 to 1,000, while in the southern hemisphere it is as 129 to 1,000. The greatest depth of the ocean is probably about five miles; while Laplace has calculated that its mean depth is about 3,000 feet. From the porous nature of the soil, and the circumstance that the stony strata forming the external crust of this world is cleaved, jointed, and often rent, channels are formed by which water passes to a considerable depth into the interior, there performing an important part in the great chemical changes constantly taking place in that laboratory of nature. Again, the vegetable and the animal kingdoms hold water largely combined; and the fluids, compounds of water and other bodies, circulating in the capillary vessels, and filling the cells of the plant, or coursing the arteries and veins of the animal, obey those laws which now become the subjects of our consideration.

Water remains liquid in virtue of some very remarkable disposition of its molecules, under the mysterious opposition of heat and cohesion; and the same may be said of all other liquid bodies.

The particles constituting a fluid are held together by so small a cohesive force that they are readily separated: by a slight blow we break a quantity of water into exceedingly fine drops, and when separated, from their mobility, they again freely flow together. We assume that in liquids the atoms are so far removed from each other, that the attractive and repulsive forces are in equilibrium, and hence the freedom with which they move about each other. An unconfined fluid is ready to yield to the action of any pressure in any direction.

It was long thought that liquids were absolutely incompressible; and to prove this, some scientific members of the *Academia del Cimento*, of Florence, filled a globe of gold with water, and subjected it to great pressure. The result of this experiment was, that the water was pressed through the gold and stood as dew upon its exterior surface. Mr. Canton has, however, shown that, though water is compressible only within small limits, and with great difficulty, yet that it has elasticity. He found that the pressure of the atmosphere compressed rain-water about one part in 22,000; olive-oil, about one in 21,000; spirits of wine, one in 15,000; and mercury, as might have been expected, only one in 33,000. Some ingenious experiments by Mr. Perkins, who sank cylinders filled with water three thousand feet deep in the ocean, by which he obtained a pressure of thirteen hundred pounds, appear to confirm the previous results.

The rebounding of a piece of slate, when thrown nearly horizontal upon the surface of a lake—as in the boys' game of ducks and drakes,—or of a musket or cannon-ball so fired, proves water to have a certain amount of elasticity.

Fluid bodies, equally with solids, are under the influence of gravitation, and, from the freedom of motion which a fluid particle has, they have no power of retaining a permanent form, but always adapt themselves to the shape of the vessel containing them, or to the surfaces upon which they rest: all lakes, seas, and rivers adjust themselves to the inequalities of the land.

It has been already shown, that, relieved from the action of gravitating force, liquids will assume a spherical form, by virtue of the cohesive force in operation between their particles. If a drop of water is taken up by a glass rod, it hangs to it in a shape approaching the spherical; but here we have the attraction of the surface of the glass operating on one side, and gravitation on the other. Over a greasy glass plate, water rolls in drops of a spheroidal form: the dew on the flower, and the drop on the wing of a water-fowl, all show that fluids are under the same laws of aggregation as solids, but that the exercise of the force is much weaker.

From these conditions it follows, that fluids are so constituted that all parts, undisturbed, must settle at the same level, no part sinking below or rising above another. If we connect together a series of vessels, no matter what may be their shapes, or how extensive the system, so that water may rise from the main channel, A B, into them, we shall find, upon pouring water into one,

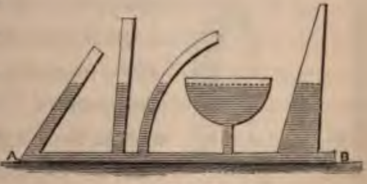


Fig. 75.

that it will rise to the same level in all the In open channels liquids cannot be made to a higher level at one end than at another always adjust themselves to a horizontal level; th servable in canals. In the great aqueducts of the the water, of necessity, was always flowing dow and thus they were inferior in utility, for waterin to the system of closed pipes which we now adop

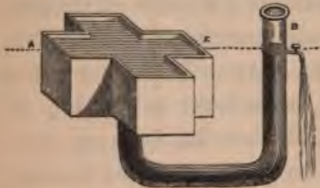


Fig. 76.

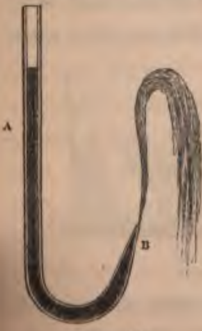


Fig. 77.

The reservoir for a modern town is placed distant hill, c is raised by power to a h in "stand-pip elevation is t tained superio of any of th which are to be supplied with water;—from this A (Fig. 76) the water flows a series of pipes, perhaps f miles, yet at the remotest e B, the liquid will rise to of the reservoir, A E. By arrangements, the water without the aid of engines, b over the highest building of fire, in almost unlimit tities, since the pressure column A (Fig. 77), the l the reservoir, would force the water from an opening at B, to nearly the same height as that column.

Upon this principle ornamental fountains are constructed, and a pretty illustration may be formed in the following manner:—Bend a glass tube, *a b* (a *siphon*), as shown in Fig. 78, and immerse one end in a vessel of water, *c*; exhaust the air from the tube by applying the mouth to the orifice at *a*, and a jet will thus be produced proportional to the height of the column. The great fountain at Chatsworth, which throws a column of water three inches in diameter 285 feet high, is supplied from a reservoir on a neighbouring hill, at an elevation of nearly 400 feet, and the supply-pipes are fifteen inches in diameter. A jet 100 feet high is found, experimentally, to require the pressure of a column of water 133 feet high.

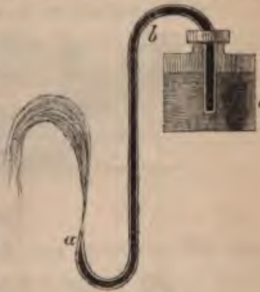


Fig. 78.

An artesian well is formed on this principle. A peculiar stratum, let us suppose it to be chalk, sand, or any porous matter, rests upon a bed of clay, or upon rocks which will not admit of the escape of the water accumulated from the deposit of atmospheric moisture, in the form of rain or dew, along the hills. This stratum of chalk or sand is also covered with a tenacious mass of clay—as the London clay, or some equally impervious

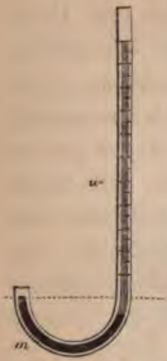


Fig. 81.

or forms a spring, if the he
fissure through which the
is less than that of a col
the saline waters of the
support. If, for example,
small quantity of a dens
(Fig. 81) in a bent tube
both ends, and then pour
of less specific gravity, th
balanced against each ot
small column of the heavy flu
port a long column of the li

All fluids in a state of complete repose, pr
zontality; that is, every part of their surfaces
tant from the centre of the earth, every atom be
acted on by gravitation, and free to arrange it
dience to that influence.

Levelling is the art of running a line along
of the earth, which shall everywhere cut the d
gravity at right angles. Upon the tendency,
of all fluids to dispose themselves in such a li
the construction of levelling instruments.

The common spirit-level is a glass tube very
with spirits of wine, and then closed by means
pipe. A B (Fig. 82) is a spirit-level, C the s
filled with air: to this instrument, for surv
poses, two "sights," or eye-pieces, are usuall
When the bubble stands in the middle of the

object covered by the cross-wires in the sights is on the same level as the instrument. There is often a limb, A F, attached, having sights also, and moving round A on a quarter of a circle (*a quadrant*) D E, divided into ninety equal parts. If it is desired to know how many degrees any object is below the level of A B, A F is turned until the cross-wires in the sights of this limb cover it, and the number of degrees between the edge of the limb F and the level E observed. If the object is above the level, the instrument is turned up; that is, the arm A D is brought up to it, and the observation made in the same manner.

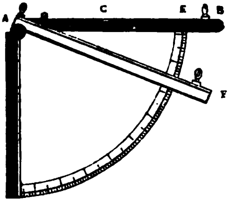


Fig. 82.

When we are told that a quantity of water, however small, may be made to balance a volume of the same fluid of any size, no matter how large, it appears exceedingly unlike the truth. Nothing can, however, be more correct, and this principle, from its startling character, is termed the *hydrostatical paradox*. The best illustration of this is

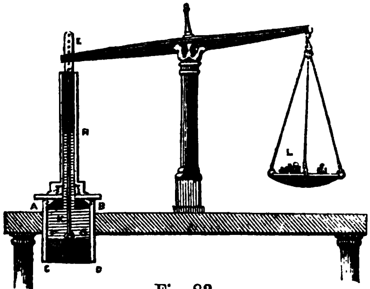


Fig. 83.

thus given.—A B C D (Fig. 83) is a cylinder, in which, moving freely, but water-tight, is a disc, F G, attached by a rod to one end of a beam: a tube H is closely fitted into the cylinder. A measured quantity, say a pint, of water, is now poured into the cylinder, which is then balanced by weights in the scale L. If now the rod is raised, to force some water into the narrow tube, the water will appear to weigh more than it did; additional weights must be added to restore the equilibrium; and if twelve inches of water are forced thus into the small tube, three pounds will be added to the apparent weight of the same volume of water.

A more striking condition than this, which relates to the pressure of fluids, and which is not immediately recognizable by unaided sense, is not to be found in the range of science. Water and all liquids press upon any object against which they come,—whether the sides or bottom of the vessels containing them, or the surfaces upon which they rest,—not merely in the direction in which gravity acts, but also sideways and upwards. The pressure on the base is in the direction of gravity; but it cannot be estimated according to the bulk of the fluid, but by the height of the perpendicular column of particles over every portion thereof. *Liquids exert a pressure which is to be measured by the height of the column, and not by its bulk.* For example: at the top of a house is a cistern holding 100 cubic feet of water, the depth of it being three feet; from this a small pipe, fifty feet long, proceeds to the lower story: now the pressure exerted at the bottom is that of a column of water of 53 feet in length, the bulk of the water in the cistern producing no result. But if we were to close up this cistern with its 100 cubic feet of water, and insert through the cover a fine tube, and into this tube pour a very small quantity of water, but which should form a tolerably high column, the pressure exerted would be sufficient to rend the cistern to pieces. The pressure on any part of the bottom or sides of a vessel, depends entirely on the depth of the fluid at any given point, and not at all on the extent of the fluid in a horizontal direction. The strength of walls, embankments, &c., to resist the pressure of water, is determined by this proposition.

A simple method of illustrating this, is to take 100 grains of water, and pour it into a glass vessel, the bottom of which is marked off into 100 squares, A B (Fig. 84); as the water covers the bottom, every square is pressed upon by water equal in weight to one hundredth part, or a grain. If we now place this 100 grains of water in a tube C, the diameter of which is equal to one of the squares, and rest it on that space, it is evident that the pressure on that square alone is 100

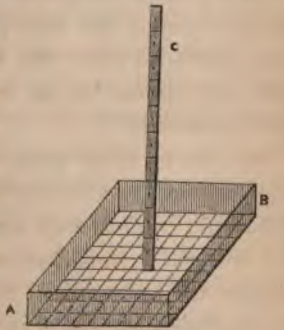


Fig. 84.

grains, and that 100 such tubes would exert a pressure on the bottom of the vessel equal to 10,000 grains. If a top was fitted perfectly tight to A B, having a hole to insert the tube C, and the vessel was filled with water, the tube containing its 100 grains would, as before, exert that pressure on the water immediately over one space; but as all the non-elastic bodies possess the property of transmitting equally in all directions the pressure exerted on any point of their surfaces, a pressure equal to 100 grains is exerted on every square, or of 10,000 grains on the whole of the bottom of the vessel. If the tube was reduced to one-half in diameter, the 100 grains of water would form a much higher column, and consequently a pressure equal to 100,000,000 grains would be occasioned over the whole by the same 100 grains of water. This peculiarity is called the *quâquâversus* pressure; and it has been proposed to apply it,—by filling horizontal tubes with water,—to telegraphic purposes, any pressure at one end being immediately indicated at the other.

The pressure in the narrow tube may be increased by mechanical means—as by working a piston,—and if the lid of the larger vessel be made moveable, the pressure exerted by it upon any external force becomes enormous. On this principle the hydrostatic or Bramah press is constructed. Fig. 85 exhibits one form of this press:—the water W, contained in the cast-iron cistern E F, is drawn, by means of the piston-rod C and handle D, up through the valve H, flowing in and filling the interior cylinder L, in which the large piston A, supporting a tube B, moving between the uprights, is placed. This inner cylinder being full, any pressure applied at D is communicated through the whole mass of water between H and L in the following ratio. If the piston C is half an inch in diameter, and the piston A one foot, the pressure of the water on the bottom of A will be to the pressure of the small piston D on the water, as 144 square inches to a quarter of a square inch, or as 576 is to 1. If by the lever D a pressure equal to two tons be given to the water under the small piston, the larger one will be forced up with the power of 1,152 tons. This enormous power may be increased to any extent, the limits to it being bounded only by the strength of machinery and materials.

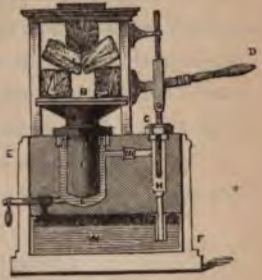


Fig. 85.

A very simple means for testing the accuracy of the above statements, is afforded by an arrangement analogous to that of the *hydrostatic bellows*, or the *anatomical siphon*. Place a bladder between two boards, having first connected it with a long slender tube, say of half an inch diameter. Water is to be poured down the pipe so as to fill the bladder when under a certain pressure, the water in the tube rising to a marked point. More water being poured into the tube, the bladder will be elevated, and by weights the pressure may be ascertained with accuracy for every inch of fluid. A cubic inch of water weighing about half an ounce, there will be a pressure of sixteen ounces on a surface of thirty-two square inches, if the column of water be but one inch high.

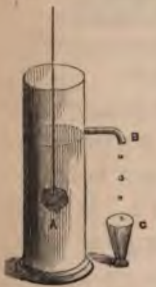


Fig. 86.

A body immersed in a fluid is pressed upwards with a force equal to the weight of the fluid it displaces. This may be thus proved:—let a vessel A have a lateral pipe B, and be filled with distilled water until some has run out through B. Place a glass, C, under the pipe; attach any substance to a beam by a string, and carefully balance it, then carry it into the water; the balance will be immediately subverted, and water will flow over through the pipe B into the glass C. When it has ceased to drop, if this water is poured into the scale-pan, it will be found to be the exact quantity necessary to restore the equilibrium of the beam. Upon this principle is founded the determination of the specific gravity of bodies,—a subject of which we have already treated under the head of Gravitation.

The pressure of fresh water is about thirteen pounds upon every square inch of level surface, at the depth of thirty feet, and so in proportion for greater or less depths. For the purpose of ascertaining the pressure exerted upon any sloping wall, or on the sides of a pond, drop a line from the water to the middle point between the water's edge and the deepest part, and multiply the length of the plumb-line under water by the extent of the side covered with water. As pressure increases with the depth, it is important that the bottoms of floodgates, embankments, walls, &c., should be much thicker than the upper parts.

The pressure of a fluid on the sides of a vessel is not dependent on the mass, but on the height at which it stands above any given point. Every particle exerts a pressure horizontally against all the sides of a vessel (Fig. 87), proportional to the length of the vertical column of water at every depth.

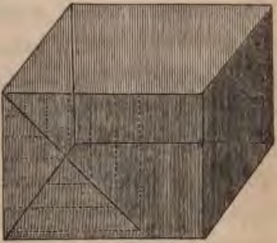


Fig. 87.

The resistance offered when we attempt to sink a body lighter than water in that fluid, proves that it presses with equal force upwards as downwards. Upon this depend the laws of floating bodies; and the bottoms of large ships, on this account, have to be built very strong.

A floating body is maintained *in equilibrio* by the operation of gravity drawing the mass downwards, and the water-pressure forcing it upwards. It is not necessary for floatation, that the material should be specifically lighter than water. If the entire mass of the solid is lighter than an equal volume of the *fluid, it* will float. A mass of iron sinks very rapidly; but the same weight of iron, rolled into sheets and joined to form a hollow vessel, swims:—iron ships and pontoons are illustrations. Man is generally a little heavier than an equal bulk of fresh water, and is, consequently, disposed to sink; but, by well filling the chest with air, and extending the arms, he renders himself lighter, and swims. Men of the Sir John Falstaff class have not "an alacrity in sinking:" they, on the contrary, float without any effort on the surface of water.

The buoyant force of water is employed to raise ships, and heavy bodies which have sunk. Air-tight vessels are filled with water, sunk, and fastened on either side of the body to be raised; the water is then pumped out, and, the upward pressure becoming greater than the gravity of the entire mass, the whole is floated. The ball-cock in our cisterns, to shut off the water when they are filled, is an illustration of this buoyant force.

HYDRAULICS (from ὕδωρ, *water*, and αυλος, *a pipe*). Under this head is comprehended the flowing of fluids through pipes, channels, &c.; the artificial means of producing motion in fluids, by means of pumps and various hydraulic machines; and the force which may be derived from fluids in motion.

When water flows in a current, as in rivers, it is in consequence of the inclination of the bed, and its motion is in obedience to gravitation, in the same manner as that of a solid moving down an inclined plane. The water in the middle of a river, or in the centre of a pipe, moves more rapidly than that at the sides, owing to the friction between the fluid and the solid matter: pipes, in consequence of this, do not discharge so much water in a given time as is indicated by theoretical calculation.

Fluids issuing from orifices have a velocity proportional to the height of the surface of the fluid above the orifice. A stream of water flowing out in a horizontal direction describes a parabola, the form of which is determined by the height of the column of water above the point of efflux. Supposing the surface of water, in the vessel A B, to be kept at a constant height by water flowing into it, and that the water flows out through openings in the side *m* and *n*, of precisely the same size, a quart measure would be filled from the jet at *n*, as soon as a pint measure from the upper opening *m*. *The quantities of water passing through equal holes in the same time are as the square roots of the altitude of the column of water above them.* The variations of density do not affect the velocities with which fluids issue from apertures:—mercury is 13½ times heavier than water, yet these fluids flow with equal velocity under the pressure of equal columns.

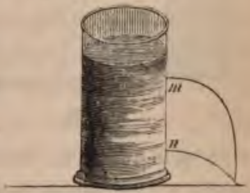


Fig. 88.

All liquid jets issuing in an oblique or horizontal direction describe parabolas, thus directly conforming to the laws of gravity for solids. This may be thus demonstrated. If we take a vessel in which the water can be kept at a constant elevation by a regular supply, and a circle is drawn, the diameter of which is equal to the whole height of the fluid, as in Fig. 89, and we allow the water to flow out through three orifices, A, B, C, each jet will reach the plane at a distance from the circle, twice as great as the distance of that point of the circle it would have cut, if it had passed out horizontally, D, E, F. And if a jet sprung from the bottom A, at any angle, the utmost height it would attain would be that point of the circle it would meet if it continued to move in a straight line; and it would then observe the law of falling bodies.

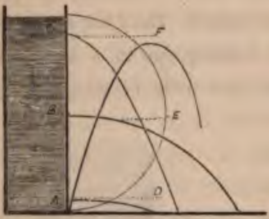


Fig. 89.

Water issuing from a small hole in the side of a vessel suffers a contraction; by which its section is diminished in the ratio of nearly five to seven: it attains its smaller section at a distance from the opening equal to about half its diameter. This point, *a b*, is termed the *vena contracta*; but if a

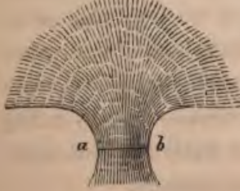


Fig. 90.

pipe two inches long is inserted, this contraction is prevented.

The water-clock of the ancients, the *clepsydra*, was constructed upon a knowledge of the laws regulating the flowing of water through small orifices. If the whole depth through which a given quantity of water sinks in twelve hours be divided into 144 parts, it will sink through 23 in the first hour, 21 in the second, 19 in the third, and so on, according to a series of odd numbers;—this diminishing rate depending on the constantly decreasing height of the column above the point of efflux.

Water flowing through long horizontal pipes, such as are employed to convey water through our streets, is retarded by the friction against the sides of the pipe: these retardations of velocity have been calculated, and they prove most useful in practice. In rivers, the greatest velocity is found at the surface and in the middle of the stream, constantly diminishing towards the sides and bottom. These points become of the highest importance where a useful application of water-power is intended; but in an elementary treatise any further notice is unnecessary.

A curious property of flowing water has to be described. Bernoulli discovered, that if a small tube is inserted into any part of a cylindrical pipe through which water is flowing, as at A B (Fig. 91), no water flowed through it, but, on the contrary, that air or water was drawn up through this lateral tube, and discharged at the larger orifice. It has been thought that this is due entirely to the pressure of the atmosphere; and in the vacuum of an air-pump the phenomenon does not occur in the same degree. It is, however, now very satisfactorily proved that water, steam, or air, flowing rapidly, have a tendency, from the exercise of cohesive force, to draw mobile bodies to their surfaces. The air in the tubes A, B, is first exhausted, the water of course rising under the influence of the atmospheric pressure; but the moment the ascending column is united with the flowing mass, a cohesive power is exerted, and the joint flow is in a great measure due to this force.

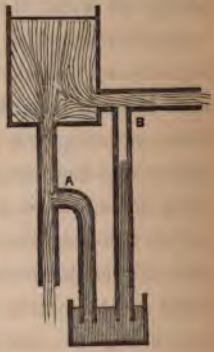


Fig. 91.

If a small pond is at the side of a canal, the surface in both being at the same level, and communicating through a narrow channel, and by the opening of a floodgate the water in the canal is caused to flow, that in the pond, from adhesion, will flow with it, and will even ascend a considerable incline under the influence of this force. Venturi applied this, in a very simple manner, to draining of land, by means of a stream running through it:—the stream was allowed to acquire sufficient velocity to carry it over an inclined surface, and to drag with it a portion of water from the lowest part of this surface. A jet of water draws towards it a current of air, and light bodies, thrown up by the side of a fountain, will be drawn into the ascending column. A ball of cork, or an egg, being placed in the middle of a jet, plays up and down within it, held by the adhesive force of the water and the inrush of air on all sides.

Arrangements of this description have recently been introduced as novelties, for the purpose of draining; and the same principle has been proposed for application in ventilating mines. From the freedom with which the particles of liquids move about each other, and also from the circumstance that they communicate, as we have already noticed, any disturbance with great rapidity, we have, as a result, the phenomena of waves. If we fill a glass vessel with water, and strike the glass at any point on the outside, the water is thrown up opposite that point, and by a series of undulations (waves) the disturbance is propagated over the whole surface. If we blow upon a surface of water, or in any way disturb it, a wave is produced. The part first disturbed sinks beneath the natural level, and the parts contiguous rise to a corresponding height above that level, and a series of alternate elevations and depressions are produced. Progressive motion is not necessary to undulation: the waves of the ocean or of a lake may progress without any onward movement of the water. This movement is easily illustrated by a stretched string: by a shake at one end we can send a series of undu-

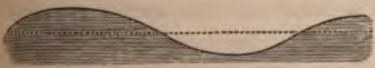


Fig. 92.

lations along the string, but none of the particles constituting the string move onward. Where the depth of the water is sufficient to allow of the undulations proceeding without interruption, the waves have no progressive motion; but if a rock rises near the surface, or the shelving shore by its shallowness prevents or retards the oscillations of the water, the waves forming in the deep water are not balanced by the shorter undulations in the shallow water, and they consequently move forward and form breakers. Thus it is, that whatever be the direction of the wind, the waves always break against the shore. Where the shore runs out very shallow for a great extent, the breakers are distinguished by the name of *surf*. Dr. Scoresby has given some interesting and important information on the magnitude and velocity of ocean waves. He assures us that the Atlantic waves, during a storm, rise to a height "about forty-three feet above the hollow occupied at the moment by the ship;" the total distance between the crests of two of the largest waves being 559 feet, which distance was passed by the wave in about seventeen seconds of time. From the observations made by Dr. Scoresby when crossing the Atlantic, and from the experiments of Mr. Scott Russell, it is satisfactorily proved that such storm-waves as the above travel at the rate of thirty-two statute miles per hour.

A closer examination of the phenomena of undulations will be found under the head of Sound.

Hydraulic Engines.—The force of moving fluids is rendered available for many important ends. Engines are moved by the impulse of water: a stream strikes against *float-boards* fixed on a wheel, placed so as to receive the impulse of the water at right angles to its radii. These are mills with *under-shot* wheels, which do the most work in a given time when the wheel moves with from one-third to one-half the velocity of the water.

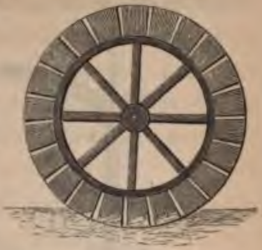


Fig. 93.

A wheel receiving water in cells or buckets, and moved by the weight of the water on one side, is called an *over-shot wheel*, which should be so constructed that the buckets may contain all the water of the stream and carry it down as low as possible before it is allowed to escape.

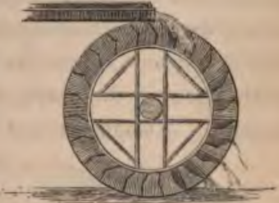


Fig. 94.

Some machines are moved by the relief from pressure produced by the motion of a stream. Barker's Mill is of this description, and the Turbine wheels involve the same principle. To understand this, let A B (Fig. 95) be a hollow cylinder moveable about a vertical axis, and having horizontal arms, so that the whole may be filled with water from the top. It will be evident, if there are no openings in the arms C, D, and the whole is filled with water, that, all

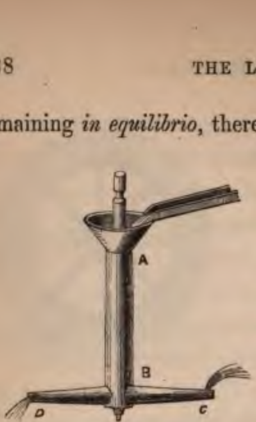


Fig. 95.

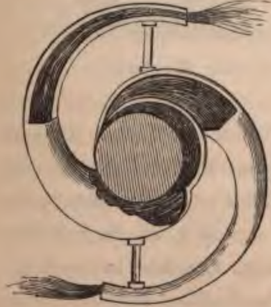


Fig. 96.

remaining *in equilibrio*, there can be no motion. If the arms, however, have openings in the sides opposite to one another, the sides on which the perforations are (the water flowing out) are relieved from pressure, and the whole pressure of two columns of water is exerted in either arm on the sides having no openings. The moving force becomes greater after the machine has begun to revolve, the water in the horizontal arms acquiring a centrifugal force by which its pressure against the side is increased. Segner's machine, used in some parts of Germany, is of the same character. A modification of this machine was patented by Mr. Whitelaw; his engine consisting of two horizontal hollow arms, of the form of the capital letter S, the water being discharged from the ends of the arms in the direction of the circle traced by their revolution, or in that of a tangent to it (Fig. 96). A mill of this kind, working with a fall of ten feet of water, the diameter of the circle described by the arms being fifteen inches, had a velocity of 387 revolutions per minute, and gave an effect equal to 73·6 per cent. of the theoretical power of the column of water.

The Turbine consists of a fixed horizontal wheel, having curved channels, A, B, in the centre of which the water enters; it diverges in every direction and escapes at the circumference. Around this wheel is a revolving circle, C D, which, by a series of curves in an opposite direction to those on the fixed portion of the machinery, receives the water from the guide-curves of A B, and is driven round by the force of the efflux. Turbines may be applied to high or low falls of water; but, although they have been used for some time on the continent, they have not yet been extensively employed in this country.

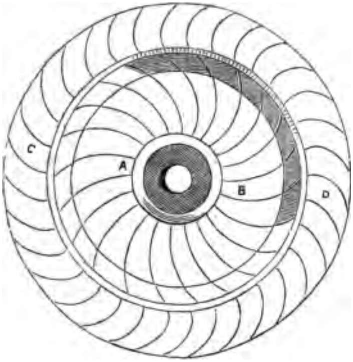


Fig. 97.

Another form of employing water pressure, is the reciprocating water-pressure engine, of which a very fine example is to be seen at the Alport mines, in Derbyshire. In these engines a column of water from 200 to 300 feet in height is brought in under a piston moving in a cylinder, as steam is in the steam-engine. The enormous pressu of such a column, forces up the piston, and moves all th pump-works attached to it in the shafts of the min Having lifted the piston to the top of the cylinder, th column of water is discharged, and of course the pisto and pump-works fall, to be again raised when the pipe forming the column are refilled.

Spiral pipes may be placed in the plane of a wheel receiving the water at its circumference, and raising it b degrees towards the axis, where it is discharged as th wheel turns; the motion of the wheel being usually derived from the same stream which supplies the pipes.

A single pipe wound spirally round a cylinder whic revolves on an axis in an oblique direction, has bee called the screw of Archimedes,—the engineer of Sicil having, as it is stated, employed such machines to rais water. The name of the *water-snail* has been applie to such a machine. If an ordinary screw is covere with a cylinder, so that it moves accurately but free

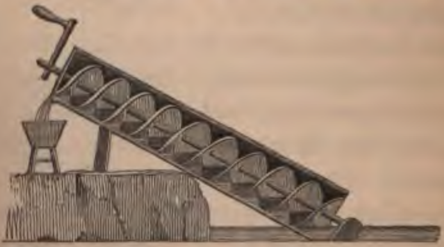


Fig. 98.

within it, it represents the form of the German water-screw (Fig. 98). A considerable loss of power arises, however, from the passage of the water between the cylindrical cover and the screw, one-third of the water, at least, running back. Several machines of this description have been from time to time introduced by ingenious mechanics; but they may, upon the whole, be regarded as engineering toys—ordinary pumps answering in all cases much better.

In the *suction-pump* we have the rise of the water produced by atmospheric pressure;—this would more properly place any description of it in connection with Pneumatics, but since it is usually employed as an hydraulic machine, it is thought advisable to include pumps in the present section.

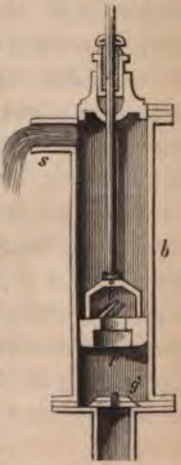


Fig. 99.

The common pump consists of a suction-pipe which descends below the level of the water in the well; of a cylinder, or *barrel*, *b*, in which an air-tight piston *p* works up and down as far as the spout *s*. On the top of the suction-pipe is a valve *g*, opening upwards, and there is another valve *i*, also opening upwards in the piston. The piston, being at its lowest point, is drawn up, and the air in the barrel is thus pumped out; the air in the suction-pipe forces open the valve *g*, and the whole space between the water and the piston is filled with rarefied air. The piston is again forced down: this pressure closes the valve *g*, and the valve in the piston opening, the air rushes through it. On again elevating the piston, this air is pumped out, and thus, the pressure of the air being removed from the water in the pipe, that fluid, by the pressure of the atmosphere acting on the water in the well, rises until it flows out at the spout. About thirty-four feet is the height to which a column of water is raised by the pressure of the atmospheric column; but if the water under this pressure flows out above the piston into the barrel, it can be lifted by the piston through a few feet more.

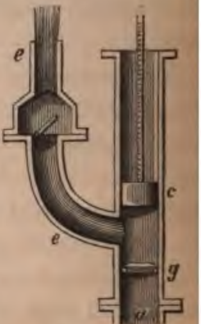


Fig. 100.

In the *forcing-pump*, atmospheric pressure plays but a small part. There is no valve in the piston *c*, but the water, raised through the suction-pipe *a* and the valve *g*, is forced by each depression of the piston up through the pipe *e e*, which is furnished with a valve to prevent the return of the fluid. The ordinary syringe is a pump with a piston moving pretty accurately in a cylinder, but no valve. All the phenomena of the pump may be easily illustrated with a glass-tube, in which we can move a greased cork by means of a wire fixed in its centre.

The siphon is another form of apparatus by which water is made to flow by the pressure of our atmosphere. It consists simply of a bent tube, *b s*, one arm of which is longer than the other. If the short arm is placed in a vessel of water, and, the mouth being applied to the end of the long one, the air sucked out, water is now pressed over, and it continues to flow, owing to the unequal pressure of the two columns in the tube. Atmospheric pressure lifts the fluid to the top of *b*, and if the length of *s* was the same as *b*, or if *b* and *s* were so placed that their orifices were on a horizontal line, the pressure of each column being equal, no water would flow; depress *s* below this line, and thus lengthen the column, the water will flow directly. The siphon is employed for many important purposes by man, and it is introduced into many philosophical toys.

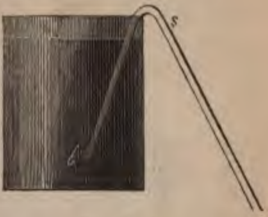


Fig. 101.

Man's ingenuity has been exercised, at all times and in all parts of the world, to devise means by which water should be raised to higher levels, or its power employed to some useful end. Hence has arisen the bead-pumps of the Chinese, the chain-pump, the bucket-pump, and numerous other arrangements, sufficiently curious, but involving no principle which has not been described.

CHAPTER IV.

LAWS OF ELASTIC FLUIDS.

Pneumatics (from *πνευμα, air*).—Having studied some of the most striking conditions of matter in solid and liquid forms, we have now to consider the physical properties of another form—the gaseous, or aeriform,—of which the most striking example is presented to us in our atmosphere.

A child at rest on a plain, on a calm summer day, would not, for some time, become conscious of being surrounded by a peculiar fluid mass. But, he moves his hand energetically to and fro, or he runs rapidly along, and he receives an impression that he is surrounded by a thin medium. Awakening sense soon convinces the youth that he is enveloped in an atmosphere consisting of peculiar gases; and eventually he learns that it holds suspended a large quantity of watery vapour. This atmosphere, in its physical character and chemical constitution, is peculiarly adapted for the necessities of the vegetable and animal kingdoms.

This gaseous envelope of the earth is supposed to extend upwards from its surface about forty or fifty miles. Since it is impossible for man actually to measure, by any of the appliances of science, its true extent, its probable limits have been approximately determined by some of the phenomena of light. Our twilight is owing to the refraction, or bending, of the rays of the sun,—after that orb has sunk below the horizon,—by the medium through which they pass; therefore the duration of the twilight affords a guide to the height of the atmosphere.

Atmospheric air varies in density with its elevation, and the more rarefied it is, the less is its refracting power; but we know not the point of rarefaction at which it would cease to refract light. The phenomena of refraction will be examined in a future page; but it appears to be important that in this place the means by which the bending of a luminous ray is made a measure of the depth of the air around us should be explained, particularly as it truly explains the causes producing twilight.

If we suppose E (Fig. 102) to represent the earth, and the circles *a*, *b*, *c*, *d*, concentric bands of the atmosphere of different densities, and consequently of dissimilar refracting powers; A B being the horizon, S the sun below it, and *e*, *f*, its rays falling upon the exterior surface of the air; we shall at once see that each ray would be slightly bent by the stratum of air *d c*, more so by *c b*, still more so by *b a*,

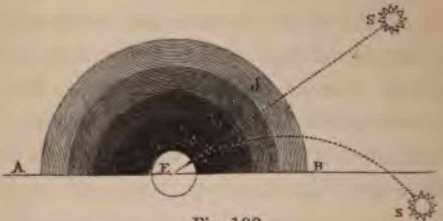


Fig. 102.

and that next the earth the eye would therefore receive the ray, after it had moved in a polygonal line, and the sun would be seen as at *s* when it was actually below the horizon. By calculating the indices of refraction, and determining the true position of the sun, we thus arrive at an answer to the problem proposed.

There are, however, some conditions of a peculiar nature to be considered, ere we can arrive at a determination founded upon the above data. It would appear that the gaseous fluid is held to the solid earth by virtue of the same, or a similar, power to that which, we have already shown, is to be detected in action over the surfaces of all bodies. This has not, however, been a point which has hitherto engaged attention;—gravitation alone has been thought sufficient to explain the phenomenon. By ascending mountains, and floating at considerable elevations in balloons, it has been determined that as this attraction diminishes, the air becomes more *thin*; not because it is rarefied by heat, but, according to one view, because the pressure of the superincumbent column is lessened. At the same time this attraction of particles is reduced, and, the air rapidly losing its capacity for heat, cold, regularly increasing with the height, is produced. It has been thought that this loss of heat would eventually place a limit to rarefaction, and even reduce the uppermost stratum of the air to a liquid state. Although these speculations are purely hypothetical, yet they have their value in reasoning upon atmospheric refraction, as probable causes leading to modifications of conditions, under which the air might possibly be confined within much narrower limits than those stated. The uncertainty of the calculations founded on the duration of our twilight, is proved by the circumstance that they give heights varying between forty-five and ninety miles. Biot, from an examination of the elasticity and density of air, infers that they sink to zero at the height of thirty miles.

Air is a fluid, and, like water, it yields to any inequality of pressure, its particles moving with the utmost freedom about each other. The flowing currents of the air, under the various rates of the genial breeze or the rushing gale, prove its attenuated fluidity.

That air has weight, is proved by many very simple experiments. When the bellows are collapsed, close the nozzle, and then endeavour to separate the boards:—we shall find that they are pressed together by an enormous weight. A column of air equal to a weight of about fourteen pounds rests upon every square inch of the surface of the board. If we take a glass flask, and weigh it full of air, and then by means of an air-pump exhaust, or by the agency of heat expand, the air, we shall find that there will be a considerable loss of weight. With a flask fitted with a stop-cock, to which an exhausting syringe can be attached, the experiment may be made with much accuracy, and it will be found that 100 cubic inches of air weigh about 31 grains.

This gaseous body possesses, in common with all matter, *impenetrability* ;—no other body can occupy the place it fills. If we take a glass vessel, and invert it in water, we shall find that the water will not rise into it beyond a certain very limited space (Fig. 103). The air, being elastic, may be compressed, but, the pressure being removed, it will immediately occupy its original space. The elasticity of the air may be proved by confining air in a bent tube (Fig. 104), and loading one arm with different weights of mercury. The spaces into which the air will be compressed will be found to be inversely as those weights. Those weights measure the elasticity of the air, and prove the

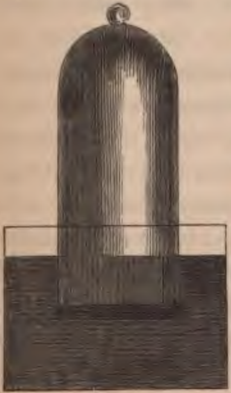


Fig. 103.

law of Mariotte, that the elasticities are inversely as the spaces which the air occupies: the densities being inversely as those spaces, the elasticity of the air is directly as its density.

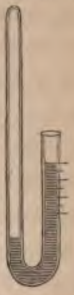


Fig. 104.

A volume of air occupying 100 measures, when compressed with a force of one pound, will be diminished to 50 measures when the pressure is doubled, and expand to 200 measures if the weight is reduced to half a pound. This law was first observed by Boyle, and more fully demonstrated by Mariotte. Subsequently Œrsted extended experiments to air compressed with a force equal to 110 atmospheres, or 1,540 pounds on every square inch, and the law is found to continue to this point,—from which we may fairly infer it to be general. Numerous experiments have been made with a view to compress atmospheric air into a liquid form; but although many other gases have been thus condensed, no such result has hitherto been obtained. Mr. Perkins stated, that under a pressure equal to 2,000 atmospheres, he had succeeded in reducing air to a liquid; but there is reason for believing that the fluid obtained was no other than water separated from the air under compression.

As we have a ponderable fluid body extending to the height of from forty to fifty miles above the surface of the earth, it is clear that a great degree of pressure must be exerted over that surface. The extent of this pressure is proved by taking a bent tube, closed at the end of its longer branch, filling it with mercury, and then placing it in a vertical position. The mercury will descend to a certain point, when it rests balanced against a column of air which is pressing upon the metal at the open end, of the same diameter as the mercury. The weight of the column of mercury between *c* and *d* is exactly equal to the weight of the column of the atmosphere. This weight is about fourteen pounds on every square inch of the earth's surface, which amounts to a total pressure of 10,686,000,000 hundreds of millions of pounds exerted by the air upon the surface of this planet. The body of a man of ordinary stature presents 2,000 square inches to this pressure, and hence a force of about 28,000 pounds is exerted upon him by the atmospheric column. This is, however, counteracted by an equal pressure in every opposite direction : and hence we are insensible of it. This is best explained by an illustration. If we take a glass cylinder—say a lamp-glass—open at both ends, and over one end tie a piece of bladder, no pressure is perceptible, because the air within the glass presses upward, or exerts a supporting power, according to the law of fluid force already explained, equal to the weight resting upon it; but if by an air-pump we remove the air under the bladder, the bladder will immediately exhibit the effects of the pressure, and eventually be torn asunder in con-

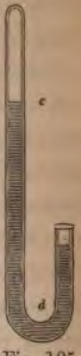


Fig. 105.

sequence. The bodies of all animals, and the delicate stems of plants, are, therefore, preserved uninjured by the equalization of atmospheric pressure.

The leathern sucker of the boy, and the adhesion of snails, periwinkles, limpets, and other shell-fish to rocks, are examples of the effect of removing the air from one surface whilst it presses upon another. The fly and some lizards, particularly the *Lacerta gecko* of Java, have an apparatus on their feet by which they are enabled to squeeze out the air, and thus, by a partial vacuum, secure that adhesion to perfectly smooth surfaces, which enables them to move freely over them in whatsoever position they may be placed. The shell of the oyster is held firmly closed by the animal exhausting a portion of the air within it:—if we bore a hole through the shell, being careful not to injure the oyster, it may be immediately opened without any difficulty. Another interesting example of atmospheric pressure, is, to fill a wine-glass with water, and, having placed a card over it, to invert it cautiously:—the glass may now be held as in Fig. 106, the water having no support but that which it receives from the pressure of the atmosphere, without any being spilled.

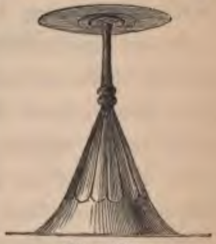


Fig. 106.

Pumps, as already described, owe their power of raising liquids, to the pressure of the air, which is equal to the support of a column of water thirty-four feet high. Similar arrangements may be employed for pumping air. Galileo relates an experiment, in which he condensed air by a syringe into a copper ball. The air-pump, however, was invented by Otto von Guericke in 1560, since which time it has been greatly improved. It consists essentially of a receiver, the edges of which are accurately ground, and, by means of a little grease, brought to fit closely a perfectly level plate of metal, having a hole in its centre, into which is fixed a pipe connected with a metal cylinder, in which a piston moves. This cylinder has a lateral opening, fitted with a valve, there being also a valve at the bottom of the cylinder. Let us suppose the piston to be pressed down and the valves closed. If we then draw the piston up the cylinder, the air above the piston is forced out, as in a common water-pump, and the air within the receiver, from its elasticity, presses open the valve and fills the cylinder. If the piston is now pressed downward, the air flows out through the lateral pipe. We have thus removed from the receiver a quantity of air equal to the capacity of the cylinder. If the cylinder holds a pint of air, and the receiver the same quantity, when both are filled by drawing out the piston, the air suffers an expansion of volume and now fills one quart; one-half of this, the portion in the cylinder, is expelled through *b*, consequently the air in the receiver is reduced one-half in density. By every stroke of the piston a reduction of density will take place, as follows:—

1st stroke expressed one-half of 1 pint : $\frac{1}{2}$ remains.
2nd ,, ,, one-half of $\frac{1}{2}$ pint : $\frac{1}{4}$,,
3rd ,, ,, one-half of $\frac{1}{4}$ pint : $\frac{1}{8}$,,
4th ,, ,, one-half of $\frac{1}{8}$ pint : $\frac{1}{16}$,,
5th ,, ,, one-half of $\frac{1}{16}$ pint : $\frac{1}{32}$ remains;

but which is expanded to occupy the whole of the space—one pint—in the cylinder; consequently, by continuing this, we at length produce a comparative vacuum. This instrument has been considerably improved, and usually consists of two barrels, in which, by means of a toothed wheel and racked piston-rods, a more speedy and complete exhaustion is effected. It will be seen, by the following figure,—in which the cylinders are represented in section, for the purpose of showing the working of the valves,—that, as the air is drawn out by raising one valve, it is expelled through the other, constructed with

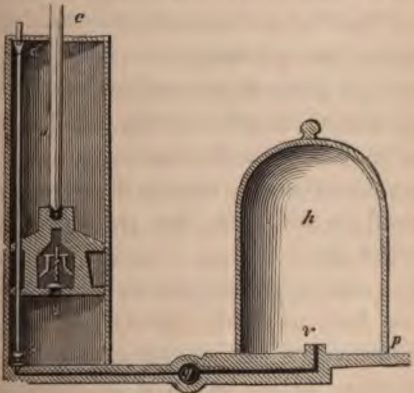


Fig. 107.

this object, as it is forced down in the opposite cylinder. By alternating the action of the pistons at every stroke, we draw air from the receiver and expel it through one of the pistons.

With this instrument a numerous set of interesting and instructive experiments can be made.—

We may prove that burning bodies are extinguished by the withdrawal of air, and that smoke falls to the ground like a heavy body. By placing water under the receiver, and exhausting it, we may separate from the water the air which it always holds in solution, and it will be seen escaping in bubbles through that fluid. We can, also, in this way prove the physical action of solid surfaces, and show that a layer of air intervenes between the fluid and the glass containing it.

If we tie a piece of India-rubber over a jar, or take a flaccid bottle of the same material, with its neck closed, and introduce it under the receiver, as we exhaust the air from the receiver, the India-rubber will be distended: this proves the expansion of air.

Take a flask closed by a cork, through which we have previously passed a glass tube drawn to a fine point, of sufficient length to reach nearly to the bottom of the flask, which is half filled with water, and place this arrangement under the receiver. The moment we begin to exhaust the air, that which is contained within the flask expands, and the water is forced out in a

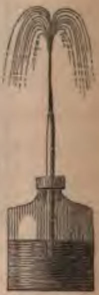


Fig. 108.

jet. This is *Hero's sphere.* We may obtain a similar fountain by forcing air into the sphere containing water by a condensing syringe, and closing it with a stop-cock: when the cock is turned, the condensed air, in its effort to expand, forces out the water with great violence.

The most striking experiment, however, proving the pressure of the air, is performed with what are called the *Magdeburg hemispheres*, from the name of the town of which Otto von Guericke, the inventor of them, was burgomaster. These consist of two hemispheres of brass, made to fit together very accurately. The edges, being smeared with grease, are brought in contact, and the cock being connected with the air-pump, this sphere is exhausted as perfectly as possible, when, so great is the pressure by which they are forced together, that they offer a resistance of extraordinary power to any attempt which may be made to separate them. In an experiment performed by Guericke himself, before Ferdinand III., thirty horses were harnessed to the hemispheres, without being able to break their contact; more power still being employed, they separated with a very loud report.

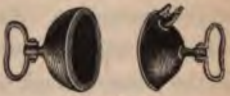


Fig. 109.

Where none of these facilities are at hand, this remarkable phenomenon of atmospheric pressure may be proved by a very simple experiment:—Take a wine-glass, and having thrown into it a small fragment of lighted paper, and allowed it to burn for a few seconds, place the palm of the hand over it: by the combustion of the paper the air is expanded within the glass, and a portion of it chemically changed; hence, as the glass cools, the remaining air condenses to its original volume, and a partial vacuum is created. The hand will now be pressed with such force upon the glass, that a considerable pull will be required to separate them. In this way the preliminary operation of cupping is performed.

The reason why beer, wine, or water, will not flow from a barrel without a second hole to admit the air, is the pressure of the atmosphere. We raise the *vent-peg*, and now, there being an equal pressure on the surface of the fluid and on the orifice through which it flows, it runs freely.

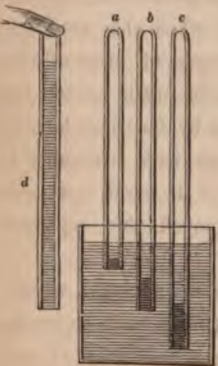


Fig. 110.

With a common glass tube open at both ends, the *impenetrability*, *elasticity*, and *pressure* of the atmosphere may be most readily shown. Placing the thumb upon one end of the tube, plunge the other into a vessel of water: the water will not rise in the tube beyond a very small space; but as we force the tube more deeply, the pressure of the water increases, and the air is compressed within smaller limits, the water occupying a little more of the tube, as shown in *a*, *b*, *c*. If the tube is raised, the air expands, and forces out the water. If we plunge an open tube to water, so as to fill it nearly, *d*, and then close the pper end, we may withdraw it from the water without y of the fluid flowing out: remove the thumb, and the hole flows out immediately. A tube of water, that does ot exceed thirty-four feet in length, may thus be supported y the mere pressure of the air.

Torricelli thought that if a column of water of 34 feet as supported by the column of air, that a heavier fluid, ch as mercury, which is 14 times the weight of water, ould not stand above 29 or 30 inches. Upon trying e experiment, the pupil of Galileo was delighted to find is idea confirmed; and from this arose the invention of e barometer, which is now so generally employed for easuring variations in our atmosphere. The most simple ay of proving that this column of mercury is but balanced gainst the air, is to take a tube of sufficient length, and, aving tied over one end with a bladder, to fill it with ercury, and invert it in a cup of the same metal: the ercury will now stand at the height of about 30 inches; ut if with a needle we make a hole in the bladder, it mmediately falls to the level of the mercury in the cup.

A tube, closed at one end, filled with quicksilver, nd inverted in a cup of the same material, forms essenially the barometer,—an instrument of the greatest imortance, as indicating regularly the changes which take lace in the pressure of the atmospheric column at the ame spot, or the diminishing pressure which we detect s we ascend from the level of the ocean.

Torricelli died, leaving this instrument, the invention of his genius, incomplete; it was, however, at once employed by Boyle in England, and Pascal in France, with great success. The latter suggested, that if the mercury were sustained by the weight of the air, it should fall upon being carried up a mountain, and he induced his relative, M. Perrier, to try experiments with the barometer at the base and on the top of the Puy de Dôme, in Auvergne. In this trial it was found that the mercury, which stood at the height of 26¼ French inches at the base, fell to 23⅛ on the summit of the mountain: thus proving the diminishing weight of the air.

When mercury and the atmosphere are both of the same temperature at the level of the ocean, the column of mercury is about 30 inches in length; ascend 936 feet, and the length of the column is but 29 inches. As the heights increase in an arithmetical series, the length of the barometric column will decrease in geometrical progression.

In making these determinations, however, a correction for temperature has to be constantly applied, since the glass and the mercury expand with an increase of temperature, and contract as it diminishes. The usual mode of proceeding is to reduce all observed heights to what they would be at the freezing-point of water, the rule being *to subtract the ten-thousandth part of the observed altitude for every degree of Fahrenheit's thermometer, which the mercury is above the freezing-point of water.* In very accurate observations correction has to be made for the expansion of the barometric tube, of the scale attached to it, and for the influence of that capillary attraction, which has been explained, producing a convexity of the surface of the mercury. This instrument has been constructed of many different forms—the principle remaining, of course, in all the same. The ordinary Torricellian barometer consists of a tube (Fig. 111) closed at one end, filled with mercury, and inverted in a vessel also containing mercury. As the level of the mercury within the tube is altered by the variations of atmospheric pressure, there must be a corresponding alteration of the level of the mercury in the cistern. Various contrivances have been introduced to regulate this. That which is most commonly employed is a cistern with an elastic bottom, which can be acted upon by a screw; a float is placed on the mercury, and every alteration of level being marked by an index, the bottom is screwed up, or the contrary, until the level is restored to its *constant* line.

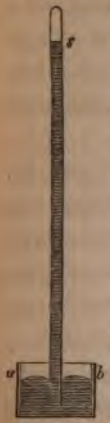


Fig. 111.

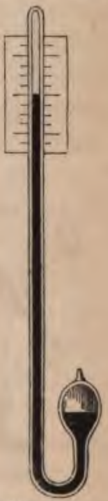


Fig. 112.

The cheaper varieties of barometers are modifications of the old siphon form, the lower branch being blown into a wide bulb, for holding the of mercury (Fig. 112). This form is, however, in strict accuracy, owing to the smallness and shape of the bulb, and, consequently, the constan tion of the level of the mercury in it; notwiths this, it is most generally employed.

The wheel barometer was the invention Hooke, and it has long maintained its reputati ordinary observers. Fig. 113 represents this inst

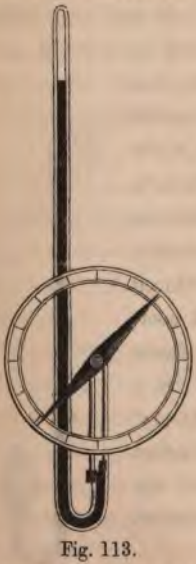


Fig. 113.

A small float of iron c rests upon the mercury shorter arm of the siph and it is suspended by a thread, which passes round cylindrical axis, carrying a As the level of the me altered, and the weight r lowered in the tube, the moves; and as the divis the circumference of the within which it moves, a amplified, very slight cha very easily read off. T strument has been made handsome piece of furnit it is, consequently, mu ployed by those who consult the barometer as a v glass. On this point it is important to unders what principle the barometer is employed to indicate meteorological changes, and to appreciate its value as such an indicator.

The fluctuations of the barometer are mainly due to alterations in the height of the atmospheric column; but we believe it is also true, that variations are to be detected, resulting from the action of aerial currents of varying temperatures, which produce a local change in density, without at all disturbing the mean height of the mass of air. The atmosphere must also vary in weight, accordingly as it is charged more or less fully with moisture; the specific gravity of dry and moist air, at the same temperature, being appreciably different. Variations of heat directly alter the pressure of the air, by forcing it to expand or allowing it to contract, and, indirectly, by the vaporization of water, or by occasioning its condensation. Now, a consideration of these points will lead to a conviction that the observation merely of the height of the mercurial column is not of itself sufficient to allow of any correct inference being drawn as to the probable condition of the weather.

It is true that a gradual rising of the mercury in general presages fine weather, and that a rapid fall almost certainly indicates a quickly approaching storm. It is not, however, uncommon to have much rain with a steadily rising barometer; to enjoy fair weather for a long time, and the column falling; and sometimes we have a tolerably rapid diminution of the height of the mercury and no particular alteration in the wind. Hence it is only by the employment of the barometer, the thermometer, and the hygrometer conjointly, that any correct predication of a meteorological change can be ventured on.

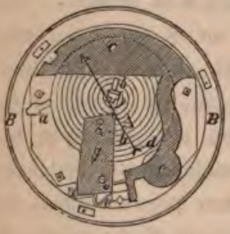


Fig. 114.

Attention has been of late directed to an instrument invented by M. Vidi, of Paris, which he terms an aneroid barometer. Its action is dependent on the effect produced by atmospheric pressure on a metal box, from which the air has been exhausted. The accompanying figure represents the interior construction of this instrument.—A is a flat circular metallic box, which is exhausted of air through the tube *a*, and which is afterwards closed by soldering. This box is made with its top and bottom of corrugated metal, by which greater elasticity is obtained, and it is firmly fixed to the bottom of the case B B. In the centre of the upper surface of the box is a solid cylindrical socket *b*, about half an inch high, to the top of which the lever *c c* is attached. This lever brings the box into a state of tension, by separating the surfaces; and it rests partly on a spiral spring *d*, and partly on two fulcrums having knife-edges—perfect freedom of motion being secured. The end *c* of this large lever is attached to a second lever *e*, from which a fine watch-chain extends to *f*, where it is attached to the arbor of the hand, the motion of which is regulated by a *hair-spring* connected with the metal plate *g*. As the atmospheric pressure is increased or diminished, so is the surface of the box elevated or depressed; and this motion is, it will be readily seen, communicated to the index by the arrangement of the levers. Notwithstanding the apparent delicacy of these adjustments, the aneroid barometer is not liable to derangement if fairly used; and from its portability it is exceedingly useful to the traveller. Its indications have been compared with standard barometers in our observatories, and they are found to have a fair average agreement.

The column of mercury in the barometer has been observed to undergo regular variations during the day: these are termed *horary variations*, and are no doubt the result of the action of the solar rays, in producing disturbances in the height of the atmospheric column. Some well-attested observations go to show that the barometer is influenced by the elevation or depression of the ocean, as shown in the phenomena of the tides. In Europe the barometer is highest in winter at nine o'clock in the morning, and lowest at three in the afternoon; and in summer the maximum occurs at eight, and the minimum at four.

The measurement of altitudes by the barometer has been already mentioned, but it is again necessary to recur to this subject for the purpose of drawing attention to the natural condition of the air itself.

The atmosphere is held to the earth by the action of gravitation, and it is maintained in its gaseous condition by the influence of calorific repulsion. It will, therefore, be evident that the stratum of air nearest the solid earth must be condensed by the influence of the gravitating force much more strongly that the upper layers can be; and, at the same time, they are pressed by the column of air above them. The first consequence of this is a regularly diminishing density in the air, by its being relieved from pressure as its distance from the surface of the earth increases; and a second is the regular reduction of temperature with its constantly increasing tenuity. As the gases constituting the atmosphere, oxygen and nitrogen, expand, they rob all surrounding bodies of their heat, and hence, the conversion of watery vapour into snow at a certain elevation, and the entire absence of any aqueous vapour in the air above the limits of the *snow-line*. The heights of the snow-line of some celebrated masses of mountains are as follows:—

The Alps	7717 feet.
Mount Etna . . .	8358 „
The Himalayas . .	14628 „
Mexico	14500 „

It will be seen from this, that as we approach the tropics the line of constant snow lies naturally much higher, and that there must be a constant tendency of the upper portion of the air to remove heat from the lower layers, which heat they derive from the earth's surface; and since gravitation diminishes with the increasing capacity for heat, it is evident that the two mysterious forces must be brought to a state of equilibrium at a certain mean height above the earth. It is well known that travellers ascending mountains suffer from the extreme cold produced by the rapidity with which the air removes heat from their bodies:—beyond a certain height it would be impossible for any animal to exist, for the air would be too *thin* to maintain the vital actions dependent on respiration, the diminishing of atmospheric pressure would occasion a fatal expansion of the fluids of the body, and by the rapidity with which the heat of the system was absorbed by the attenuated medium, it would perish of cold.

Although the phenomena due to heat will receive particular attention in the proper place, it appears necessary that the atmospheric conditions due to the operation of this physical agent should have our consideration in the present chapter.

It has been proved that the solar rays lose about $\frac{1}{5}$ of their caloric in passing through a column of 6,000 feet of the atmosphere; but this is near the surface of the earth, a much smaller quantity being of course lost in the upper and more attenuated regions of the air. The atmospheric temperature is, however, chiefly due to the heat it derives from the surface of the globe. This occasions a constant circulation of the air,—that which is next the solid surface becomes warmed and ascends to give place to the descending column of cold air: and to this are due those aerial currents which we call WINDS.

A very familiar illustration of the production of winds is afforded by partially opening the door of a warm apartment. If we place a burning taper at the upper part of the opening, the flame will take an outward direction, but at the lower part it will be blown inward, the warm air passing out above and the cold air rushing in below.

By the unequal warming of the air resting on different parts of the earth's surface, sometimes on the land and sometimes on the sea, these ever-changing currents, the winds, are produced. The land communicates heat quicker than the water does, consequently it warms the air rapidly; this warm air ascends, and the air cooled by passing over the ocean rushes in to supply its place. This gives rise to the sea-winds which prevail on the sea-shores of islands.

As the air receives warmth from the land, it is also receiving constant additions of aqueous vapour, owing to the evaporation which the heat occasions; consequently, in regarding the atmospheric pressure, we have to consider the gaseous pressure and the vapour pressure; but, as we have already shown, this vapour column is an exceedingly short one compared with the gaseous one.

From the gradual condensation of this vapour, clouds are formed, and a rapid condensation produces rain. The enormous quantity of water thus held suspended or mixed with the air, is often proved to us by the large quantity which falls during a heavy shower. The condensation of aqueous vapour, by altering the temperature of the air, may be looked upon as one of the causes producing tempests. The most remarkable winds are the *trade-winds* and the *monsoons*. These tropical winds blow with great regularity constantly from the east towards the west, both in the northern and southern hemispheres. Our sailors, on a voyage to America, steer southward from Madeira to the tropics, when they are carried westward by this current. On the north of the equator these winds have a direction from the north-east; on the south of the equator they tend from the south-east. Their origin is due to the powerful heat of the torrid zone, which rarefies the air of that region. The air thus rarefied rises, and, to supply its place, the colder air from the temperate zones moves towards the equator. However, these north and south winds pass from regions where the rotatory motion of the earth's surface is less, to those where it is greatest. If the earth did not turn round, they would be north and south winds; but as they approach the equatorial regions they acquire additional velocity, and are bent into north-east and south-east winds.

The trade-winds would blow regularly round the whole globe within the distance of about thirty or forty degrees from the equator each way, if the space within these limits were all covered with water; the larger expanse of ocean they blow over, the more steady the trade-winds are, but the uneven surface and unequal temperature of the land diverts and disturbs them. The following small map represents the region and general direction of the trade-winds.—A (Fig. 115) represents the region of the north-east trade-wind, B that of the south-east, C the region of calms, and D that of the monsoons.

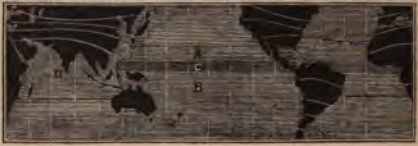


Fig. 115.

The monsoons belong to the class of periodical winds: they blow half the year from one direction, and the other half from another opposite to it. When they shift, a season of variable winds and violent storms prevails, which renders navigation in those seas at such times very dangerous. The monsoons are indeed trade-winds, blowing with some constancy for six months of the year in contrary directions. The south-west monsoon in the northern hemisphere, and the north-west monsoon in the southern hemisphere, prevail when the sun is perpendicular to their respective regions; hence, it is satisfactorily shown, that they are immediately dependent upon the influence of the heat of that luminary. Winds are therefore caused—

By the ascent of air over tracts of country that are more heated by the sun's rays than others;

By evaporation causing a change in the density of the air;

By a deposit of moisture causing an actual decrease in its volume.

The velocity and force of the winds is briefly shown in the following table; the measurements being obtained by instruments called anemometers, of which there are many varieties, all of them, however, depending upon the indication afforded by the pressure of the wind upon a carefully adjusted surface.

Miles per hour.	Force on one square foot in avoirdupois lbs.	Character.
1	·005	Scarcely perceptible.
5	·123	Gentle breeze.
15	1·107	Brisk breeze.
25	3·075	Very brisk.
35	6·027	High wind.
50	12·300	Storm.
80	31·490	Hurricane.
100	49·200	Violent hurricane.

Professor Dove, who has devoted considerable attention to the phenomena of the winds, writes as follows on some of the changes induced by these currents:—

"When the *south-west* wind, constantly increasing in force, at length predominates, it raises the temperature above the freezing-point; and the snow is, consequently, converted into rain, whilst the barometer falls to the lowest mark. The wind then veers round to the *west*, and the dense flakes of snow indicate the accession of a colder wind no less than the rapid rise of the barometer, the motion of the weathercock, and the thermometer. A *north* wind clears the heavens, and a *north-east* wind effects a maximum of cold and of the barometer. This, however, is gradually lowered, and the occurrence of fine cirri indicate by the direction from which they come the advent of a more southern wind, which is soon felt by the barometer, although the weathercock may not have experienced any change, and may still be pointing due east. The *southern* wind, however, continues to drive the eastern current downward, and on a decided falling of the mercury the weathercock points *south-east*, when the heavens again become gradually overcast, and, with the increase of heat, the snow that had fallen with a *south-east* and *south* wind, is again converted into rain by the *south-west* wind. The same then begins again, the change from the east to the west course being generally characterized by the occurrence of a short interval of fine weather."

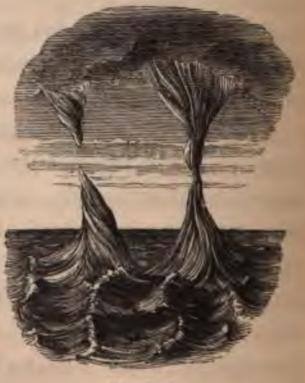


Fig. 116.

We have already spoken of the peculiar revolution of the storms of the tropics: of a similar character to these are whirlwinds and waterspouts. The air often in comparatively calm weather acquires a whirling motion, as we see by the manner in which dust, dry leaves, and sand are taken up and whirled along.

The usual manner in which a waterspout forms, is, that a mass of cloud acquires a revolving motion, by which the vapour assumes a conical form, with its vertex tending downwards; at the same time the whirling column of air raises the water up into a cone; which goes on revolving until it unites with the cloud, when they progress rapidly as a united column of air and water. These curious phenomena are generally caused by the struggle of two currents of air moving in opposite directions.

Although some allusion has been already made to the distribution of vapour in the air, it appears to be necessary to a clear understanding of many natural phenomena, that the means of ascertaining with correctness the amount of moisture in the atmosphere should be described, and the actual variations thereof determined. The evaporation of water is a sufficiently familiar phenomenon. If we place a vessel of that fluid in the sunshine, it reduces in quantity—a portion has passed off into the atmosphere in a state of vapour, and is as invisible as the air itself. Every portion of the surface of the earth containing moisture, and the entire ocean, constantly, during the hours of sunshine, send forth vapoury water. This diffused vapour only becomes visible to us when it returns to its fluid state:—its small water-particles then form cloud or mist—or it is deposited as dew or rain.

The hygrometric character of the air is, of course, constantly varying; and for the purpose of measuring these variations many instruments have been devised, which are called *hygrometers*. By a little skill and attention several things may be so adjusted as to indicate the variations of dryness;—hair, whalebone, straw, wood, paper, and other organic substances, alter in size as they absorb or part with moisture. If, for example, we fix against a wall a long hair or a piece of catgut, and hang a weight at the end of it, it will be observed, as the air becomes dry or moist, that these substances alter in length, and, by marking a scale, the two extremities of which are determined by observation, when the air is very dry and when it is saturated with moisture, it will be found easy to measure the variations. Instruments, however, of this class, of which the best is that known as Saussure's *hair-hygrometer*, are not to be so strictly relied on as some others which depend upon the rate of evaporation.

We may arrive at very correct results as to the amount of watery vapour in the air, in the following manner. Cool the bulb of a good thermometer by dropping a little ether upon it, watch the moment that a ring of dew appears upon the upper part, and observe the degree at which the mercury stands in the tube. This is called the *dew-point*: it is that temperature at which the atmosphere would be saturated with moisture, by the quantity of aqueous vapour existing in the air at the time of observation. A very beautiful instrument, of great accuracy, has been constructed upon this principle by Professor Daniell. It consists of a curved tube terminating in two bulbs, *a*, *b* (Fig. 117). The bulb *a* is either gilt or covered with a little

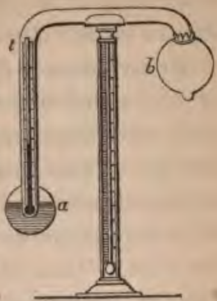


Fig. 117.

thin platinum foil: this bulb is half filled with *ether*, and contains a small thermometer, which passes into it. The bulb *b* is wrapped in a piece of fine linen, and the whole apparatus is rendered perfectly air-tight. If ether is dropped upon the ball *b*, it will, by the evaporation of this volatile spirit, be rapidly reduced in temperature, the rate of evaporation of the ether varying with the condition of the atmosphere. The whole tube being filled with the vapour of the ether in *a*, this is condensed in the bulb *b*, and evaporation of that in *a* is increased—it thus robs the glass and its metallic coating of heat, and at length a delicate dew suffuses the bulb;—the thermometer will now indicate the point at which this condensation takes place, and the thermometer on the stand of the instrument will show the natural temperature. To give an example: we will suppose the thermometer to stand at 76°, and that when the dew forms the temperature is reduced to 38°, the difference between these two points being 38°: these are marked as the *degrees of dryness*. The *dew-point* is therefore 38°, at which temperature the air is incapable of taking up more water, it being already saturated. By observing the rate of evaporation, as measured by a thermometer kept constantly wet with water, and comparing this with another, the bulb of which is dry, we arrive at the same result. This process is called the observation by the *dry and wet bulb thermometer*.

We say the *air is dry*, when water evaporates quickly—or any wetted surface dries rapidly;—and that it is *damp*, when moistened surfaces dry slowly, or not at all, and the slightest diminution of temperature occasions a deposit of moisture in the form of mist or rain. By these expressions we intend only an approximation to the truth. When we call the air dry, it contains much moisture, and when damp, it is not at its point of saturation, since the temperature must be reduced to occasion any dew.

The quantity of watery vapour in the air is at its minimum in the coldest months, and it increases until July, when it reaches its maximum, and it then decreases to the end of the year, constantly varying with the temperature.

Dew, it will now be understood, is only the condensation of the moisture contained in the air, upon surfaces which are colder than the atmosphere. *Mists* are of a similar character: a change of wind reduces the temperature below a point at which the air would be saturated with watery vapour, which is then condensed.

Clouds are, also, mists, formed in the upper regions of the air. It has been proved by very careful observations, that the reason why clouds, being condensed water, float, is, that they consist of small vesicles of water, which, like the soap-bubble, float until they become of greater specific gravity than the air by which they are surrounded.

Clouds have been divided into several varieties.—The *cumulus*, which is a dense cloud rising from the horizon, like mountains of snow, grouping themselves in most picturesque masses, and which, when illuminated by the setting sun, present the most gorgeous appearance. The *cirrus*, a feathery cloud, which spreads out over the sky in fine filaments. The *stratus*, a stratified cloud, which is often seen to stretch out in long streaks around the horizon.

These are the principal forms, but they pass into some others;—their combinations have been named by Luke Howard, the *cirro-cumulus*, the *cumulo-stratus*, &c., and the accumulation of these forming the rain-cloud, the *nimbus*.

The quantity of rain which falls, varies with the locality, and is of course determined by many physical conditions; insular countries, like our own, having more rain than those situated in the centre of large continents; the quantity of rain falling, and the number of rainy days, regularly decreasing with the increase of distance from the sea, unless in mountainous districts. Instruments called *rain-gauges*, are employed to measure the quantity of water which falls. These consist of a funnel, the rain received in which falls into a box of the same diameter, and the depth of water is measured and expressed in inches.

It now becomes necessary that the laws which regulate the motion of gaseous matter under varying conditions should be attentively considered.

It is already understood that gases are distinguished from fluids by their *expansibility*,—their power of spreading themselves out in *all directions*,—fluids only spreading out laterally. It will assist our view of the dynamics of gaseous bodies, if we have a distinct conception of their *compressibility*.

As far as experiment enables us to judge, we can declare that all gases and vapours may, by depriving them of heat, and subjecting them to a sufficient amount of pressure, be reduced to the liquid, and eventually to the solid form. A few gases,—oxygen, hydrogen, and nitrogen,—have hitherto resisted compression, and hence they have been called *permanently gaseous bodies*. We know, however, that in many chemical compounds,—as, for example, in nitrate of potash (saltpetre),—we have oxygen, hydrogen, and nitrogen, in the form of solid matter; and we therefore infer, that we may eventually reduce, by mechanical means, those gases to the solid state.

The most recent researches in this interesting branch of physical inquiry are those of Dr. Faraday, who says, in renewing his original investigation, that "considerations arising out of the apparent simplicity and unity of the molecular constitution of all bodies, when in the gaseous or vaporous state, which may be expected to pass according to some simple law into their liquid state, and also the hope of seeing nitrogen, oxygen, and hydrogen either as liquid or solid bodies, and the latter probably as a metal, have lately induced me to make many experiments."

The following are the gaseous or vaporiform bodies which have been rendered either fluid or solid, by extremely low temperatures, or by pressure.

	Temp. of Fluidity. Deg. of Fahr.	Temp. of Solidification. Deg. of Fahr.	Pressure in Atmospheres employed.
Olefiant Gas	—106		
Hydriodic Acid . . .	. .	—60	
Hydrobromic Acid . .	—100	—124	
Fluosilicon	—106		
Phosphuretted Hydrogen	—0	. .	3
Fluoboron	—131		
Sulphurous Acid . . .	. .	—105	2
Sulphuretted Hydrogen .	. .	—122	
Carbonic Acid	—70	—148	36
Euchlorine	—75	—110	
Nitrous Oxide	. .	—150	
Cyanogen	—30	—100	
Ammonia	. .	—103	
Arseniuretted Hydrogen .	—75		
Chlorine	—60	. .	4
Nitrous Acid	—45	. .	50

Further consideration of the laws regulating these different conditions of matter are reserved for the section on Heat.

These facts prove, in the most distinct manner, that our atmosphere and all gaseous bodies are very *compressible*, and that they are *infinitely elastic*: we know of no amount of rarefaction by which any chemical change can be produced in these aeriform fluids.

The motion of gases among themselves has been already noticed in the first chapter of this work, that section being chosen to describe what appears to be a peculiar exemplification of attractive force exerted between bodies of different densities. It is not necessary, therefore, to refer any further to the law of diffusion, than to draw particular attention to the fact, that it is to this agency in particular that the removal of gases from the surface of the earth is effected, which in a concentrated form would be injurious to animal life.

The laws of motion, which apply to the flowing of liquids, fully apply to gases. In flowing, however, through tubes and orifices, there is less adhesion in the case of air than in that of water, and the lighter gases flow with the greatest ease and velocity. An apparatus, commonly made by glass-blowers, having two bent tubes proceeding from the sides of a bulb containing water, the whole turning freely on a pivot, over a spirit-lamp, illustrates the fact for vapour, already explained in the case of water. If heat is applied to the water in the bulb, steam is formed, which, rushing out of the tubes, gives a rapid rotatory motion to the toy. Here, a flow of vapour from a lateral orifice produces a reaction on the opposite side; the pressure becomes unequal, and motion results.

The current of air, or the ascent of smoke, through a chimney, is the result of rarefaction. When the air in a chimney and that of a room is of the same temperature, there is no motion; and, as often occurs, if the external air remains of the same temperature, while that of the room is warmed, there being, owing to the tightness of the doors and windows, no regular supply of fresh air below, the warm air of the room will ascend through the chimney, and the cold air descend by the side of it—two currents readily circulating through one tube;—and this is rendered disagreeably sensible to us by the strong smell of soot in such an apartment. The direction of the arrows in Fig. 118 will show the lines of the current, descending the chimney, and circulating round the apartment. When we light a fire in the grate, the warm air and vapour at once ascends, and gradually it warms the whole length of the chimney; and, provided there is a supply of fresh air from below by the door or windows, a strong draught is produced, one current only now flowing upward, in ordinary cases. In the funnels of steam-packets and of locomotive engines, there is reason for believing that, when in motion, there is a downward current. Much has been written and said of late on the subject of ventilation, and numerous are the

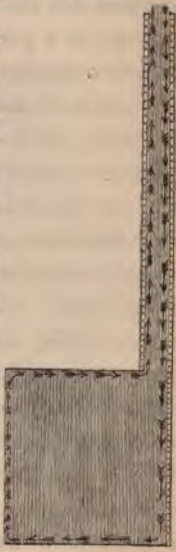


Fig. 118.

plans with which the public have been treated, all promising to secure the perfect ventilation of rooms, and the absence of all annoying currents; few, however, have been successful, their failure in nearly all cases having arisen from the complicated machinery introduced to perform a very simple operation. In obedience to a natural law, light air ascends, heavy air descends, and by heat we can give to air any degree of lightness, and consequently produce any degree of ascensional power. It is, of course, important that the air of a room should be changed as frequently as is possible, since human beings very rapidly deteriorate the atmosphere in which they are confined, and it is injurious to health to expose the body to unequal temperatures. All the supply of air to the fire-places in our apartments, as they are usually constructed, is derived from the openings of the doors or windows, and hence, not unfrequently, when seated in the line of the current, we suffer from cold on one side, while we are over-heated on the other. Those who advocate making our rooms nearly air-tight, and supplying air by a system of tubes from without, are wrong, since the result is, that the body thus *stoved* becomes as delicate as any exotic in a hot-house, to which the healthful breath of heaven is death. When, at the coldest seasons of the year, it is comfortable to sit in a very warm room, the chance of draughts may be lessened by having a channel under the fire-place, communicating with the external air; but at all times, as full and free a circulation of air as can be secured by the largest windows and the widest doors, is serviceable in promoting robust health.

The ventilation of coal-mines is a subject which has demanded much attention, from the very melancholy catastrophes which, from time to time, take place, owing to explosions of fire-damp. Those mines which are in the best order, have usually two shafts, one of which is called the *upcast*, and the other the *downcast* shaft; the object of these being to secure a circulation of air through every part of the mine. To many mines one shaft only has been sunk, and the circulation of air is effected, *but imperfectly*, by dividing it. Fig. 119 represents a sec-

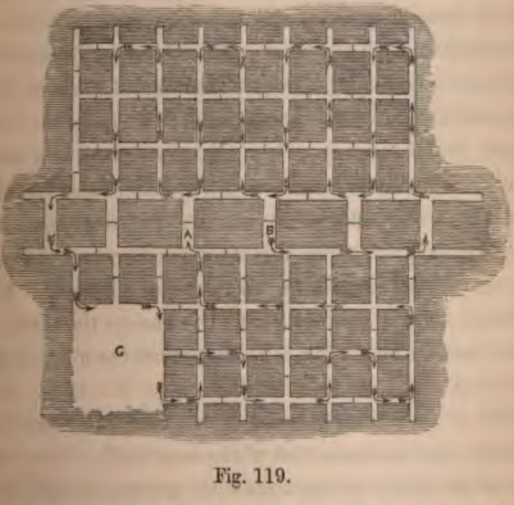


Fig. 119.

tion of the workings of a coal-mine with two shafts. Reference to this figure will materially assist in explaining the conditions, under which explosions occur, and by which also ventilation is usually effected. A B represent the up- and downcast shafts, communicating with the main passages of the workings; and from these, lateral ways are wrought, leaving thin walls or pillars of coal to support the superincumbent strata. Supposing these channels to be all worked through, as shown in the figure, it will be perceived that it will be easy to secure an efficient circulation of air in the line of the arrows through all these passages, the air descending by A, and ascending by B, after having circulated through the mine. But often the lateral workings are not carried through into another main channel, and they thus become bays, in which the air stagnates; and frequently, when one portion of a seam of coal is worked out, the supporting pillars are removed, and the whole allowed to fall in; forming then what is called a *goaf*, G: in this, to a greater extent than in the lateral workings, the air becomes stagnant. Now, although means may be adopted to change the air in the principal channels, it is a long time before the air in lateral workings or the goaf is removed.

Fire-damp is a carburetted hydrogen gas, arising from the chemical decomposition of the coal itself. This, when mixed in certain proportions with atmospheric air, forms a highly explosive compound, and the miner, communicating to it the heat of the flame of his lamp or candle, occasions its combustion, which, proceeding with terrific violence, sweeps down all before it. By this combustion the carburetted hydrogen is converted into carbonic acid; and those who escape the ravages of the explosion, fall victims to the deadening influences of the *choke-damp.* Those dreadful accidents frequently occur from the following causes.—In some cavity in the seam of coal, carburetted hydrogen gas has been long forming, and it eventually (by its pressure, perhaps) produces a rent in the wall of the goaf, or some other part of the mine through which it escapes. Being lighter than atmospheric air, it accumulates in the roof of the goaf, or the workings; eventually a change in the barometric pressure occurs, and the explosive mixture flows out into those parts where miners are at work, and it is by some unfortunate cause ignited, when the results are fearful.

Three methods in particular have been adopted to ventilate such mines. One has been the construction of a furnace in the upcast shaft, which is supplied with air entirely from the mine, and with those which are well constructed a current of almost any velocity can be produced. Another method is that of allowing a jet of high-pressure steam to flow into the upcast shaft. This, like a jet of water, has the property of dragging air after it in a remarkable manner, and of thus producing a very strong draught through all the air-ways. The third plan is to set air into rapid motion, by means of a horizontal wheel, arranged somewhat like the turbine (Fig. 97), the centre being connected with the shaft of the mine. This wheel, or chambered disc, being put in rapid revolution, discharges the air from the openings in its periphery, with great velocity, in obedience to the laws of centrifugal force; and as this escapes, a fresh supply is drawn from the mine, and thus a current of considerable power is generated.

Among the more curious phenomena connected with the flow of air, we have a result first noticed by Clement Desormes. This experimentalist observed, when an opening was made in a vessel of compressed air, and it rushes out with violence, that, if a plate of metal or wood be presented against the orifice, after overcoming the first repulsive action of the jet, it is attracted, and rapidly oscillates within a short distance of the opening.

This experiment may, however, be very simply tried.— On placing the fingers closely together, and the hand horizontally, with the palm turned downwards, a series of intervals will remain between the joints. If we apply the mouth to the space between the index and the middle finger, and blow with as much force as possible, and then place a piece of paper, three or four inches in diameter, it will be sustained against the force of gravitation as long as the current of air is energetically maintained; on ceasing to blow it will fall to the ground.

The current of air, on escaping through the opening against the opposing disc, expands itself into a thin sheet of air, flowing out between the two surfaces, and it then exerts a lateral attractive force, precisely similar to that exhibited by the sides of a strong jet of air, steam, or water. This explanation is not the one usually given; but it is much less complicated, and, it is believed, will be found completely sufficient to explain the phenomenon.

To this department of science belongs the examination of the laws regulating the pressure of steam at various temperatures; and the important improvements which have been made in the application of steam power, are referable to a close examination of all these apparently abstract phenomena. Some of the conditions of steam will be noticed under the section devoted to the consideration of the laws of Heat, and beyond these it is thought that it would be unwise to introduce these high-class examinations, aided, as they must of necessity be, by mathematics, in the present work.

CHAPTER V.

THE SONOROUS MOVEMENT OF BODIES.

Acoustics (from ακουω, *to hear*). *The production of Sound in general.*—The Ear forms one of the most important channels of connection between the mind and the external world;—without this organ we should have no perception of sound, and the world would lose a large amount of those pleasures which we enjoy through this medium of sensation.

As we appreciate musical harmony and every variety of sonorous undulation by the ear, a brief description of the structure of that organ appears a proper introduction to the Physics of Sound. The external ear consists of a funnel-shaped cartilaginous mouth (Fig. 120), called the *auricula*, or *pinna*, and sometimes the *ala*, or wing; the pendent part being named the *lobe*. The *auricula*, receiving many vessels and nerves, is exceedingly sensible, and is reddened by even slight mental emotion. The auditory passage within the external ear, called the *meatus auditorius*, leads to the internal organs, extending to the membrane of the *tympanum*, or *drum*, which covers the cavity of the tympanum, a small opening in the hardest part of the skull. This communicates with the mouth by the *Eustachian tube*, through which it is filled with air, the *membrana tympani* preventing, unless it is injured, the admission of any air through the external ear. The cavities of the internal ear, or labyrinth, are hollowed out of the temporal bone, and contain a very thin and limpid fluid, in which floats the *acoustic* or *auditory nerve*, divided into two bundles of fine threads; which is the most essential part of the organ of hearing, as even the membrane of the tympanum may be injured, without a total loss of hearing.

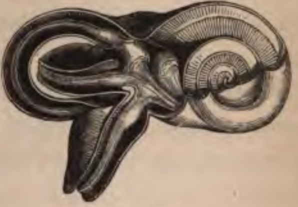


Fig. 120.

The external ear receives the waves of sound, and transmits them along the *meatus auditorius* to the *membrana tympani*, which is set into a state of corresponding vibration. These pulsations are continued by three small bones, the *malleus*, the *incus*, and the *stapes*, connected with the *os orbiculare*; the whole forming a singularly connected chain between the *foramen ovale* and the membrane of the tympanum. There are many parts of exceeding delicacy, and semicircular channels, which appear to enable us to distinguish the direction of sound, which have not been described, from a wish to confine attention to the principal parts of this wonderful construction. It must, however, be stated that the skull itself is admirably adapted for receiving those impulsive tremors on which sounds depend, the phenomena of which must be now described.

A clear appreciation of wave-motion is necessary to understand the philosophy of sound, and also of those theories of light and heat which involve the idea of undulations.

If we throw a stone upon water, it of course depresses the spot on which it falls; and as the particles return to their position, circular waves spread themselves in all directions from that spot as a centre. These waves consist of alternate elevations and depressions of the fluid: the water itself does not share in the advancing motion of the wave, for a floating body is moved up and down, but not onward, by the undulations. Waves depend upon the force of gravity;—an elevation or a depression is produced in the water, and the particles of the fluid are compelled, in obedience to this power, to restore the disturbed equilibrium, and produce anew the horizontal plane. These movements are termed *undulations*, *vibrations*, and *oscillations*; they are divisible into two kinds. Fasten a cord at one end, hold the other in the hand,

and having strained it tight, move the end you hold sharply up and down, and a wave will be formed, which will proceed along the string. This is a *progressive vibration.*

Secure a piece of catgut at both ends, *b b*, and then strike it, or, raising it at two points, set it suddenly free, and we form *stationary undulations.* The string will alternately rise and fall, the elevation becoming the depression, and the contrary; certain points of rest, *a a*, will be observed, which are called the *nodal points*, or lines of repose. We may illustrate this with a violin or an Æolian harp. If we place upon one of the strings several pieces of paper, *b*, *c*, *e*, *d*, and lightly touch the string with a bow, the undulations of the string will be shown by the pieces of paper being thrown off, as they are situated at the point of elevation or depression of the waves. We may determine the order of vibration, and consequently the nodal points, by touching the string with the finger of one hand, *a* (Fig. 122), as with the other hand the string is struck with the bow. The small pieces of paper, *b*, *c*, *d*,

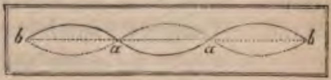


Fig. 121.

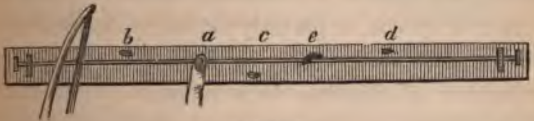


Fig. 122.

will then fly off from the vibrating portions, but the piece situated at that point of division, *e*, which corresponds with the point of rest made by the finger, will remain undisturbed.

Solid, fluid, and aeriform bodies admit of being set in vibration. Fine wires are susceptible of three kinds of vibration.—*Transverse* vibrations are produced by pulling a stretched wire by the centre, and suddenly letting it go; *longitudinal* vibrations, by straining a wire with a weight, raising it, and allowing the weight to fall; while *rotatory* vibrations are formed by twisting the wire by the weight, and setting it free.

Experiment and theory have determined the following principal laws of these vibrations:—Like the oscillations of the pendulum, they occupy each an equal duration of time, and are, therefore, said to be *isochronous*; and, secondly, the number of vibrations become more rapid if the force of tension, or the body's elasticity, be increased.

Experiments show, that in equal times the number of vibrations in a uniform rod is inversely as the square of the vibrating parts. If we fix a steel wire, *a*, in a vice, B, of such a length that it vibrates from *c* to *c*, when struck with a certain force, twice in a second, and then reduce its length one-half, it would make eight vibrations; or, if shortened to one-fourth, thirty-two vibrations in the same time. The rod

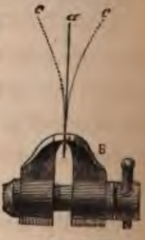


Fig. 123.

or rods thus set in motion describe variously curved lines; and, if a polished knob is fixed on the free end, these different curves are clearly seen. This principle is involved in Wheatstone's *Kaleidophon*, which consists of a circular base of wood, about nine inches in diameter and one inch thick. Into four sockets, *a*, *b*, *c*, *d*, are screwed as many vertical steel wires, about twelve or fourteen inches long. One rod should be square; another, a cylindrical one bent; and the others, cylindrical of different diameters; the tops of each carrying quicksilvered beads. When any of these rods are set vibrating, the instrument being placed in the sunshine or a strong light, the luminous images will form continuous and returning curve lines in a state of constant variation.

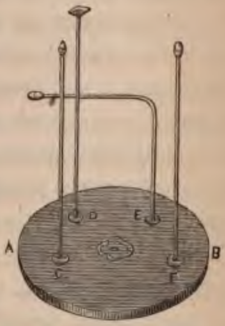


Fig. 124.

It will be evident, if we take tense wire, that the vibrations of stretched lines partake of the character of the oscillations of the pendulum. This may be studied easily by stretching a wire horizontally (Fig. 125), raising the wire at *b*, and setting it free,—it will, by virtue of its elastic force, return to its first position; but, like the pen-

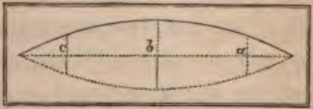


Fig. 125.

dulum, it has acquired momentum, and is carried on with decreasing velocity to the opposite end of the line *b*, when its cohesive force reduces its elastic force to nothing. It then returns from *b*, oscillates towards *a c*, and thus moves between the two points of *b*, until its motion is extinguished, and it again rests in its longitudinal position.

When a water-wave strikes against any solid body, it is thrown backward—this is called a *reflexion of the wave*;—the reflected waves taking their forms from the outline of the surface against which the primary wave impinged. Obtaining a vessel, narrow compared with its length, and placing it upon a level surface, fill it with mercury, then by slightly elevating one end of the box, produce a wave, which will traverse steadily to the opposite end; striking against the wood, the wave is thrown back, or *reflected.* The wave was started by a certain force applied; as it strikes against the end of the box, a portion of that force is destroyed, and the reflected wave is neither so high nor so long as the primary wave. In this way, wave phenomena in fluid bodies, which really differ in no essential particular from undulations in solid ones, may be conveniently studied.

If we give an impulse to the fluid by a blow at both ends of the box, two waves will be formed, which will intercept each other. If they meet in exactly opposite directions, and have moved in equal times, so that their points of elevation coincide, a wave of double the height of the single one will occur; or if the two depressions meet, a depression of double depth will be produced; but if an elevation meet a depression, the wave is annihilated:—this is termed the *interference* of waves.

Precisely similar results may be produced in a circular vessel, by producing a disturbance from the centre, or from two points a little distant from the centre; or the experiment may be easily tried by placing a large basin of water on a cane-bottomed chair, and producing regular or irregular vibrations by striking the elastic cane.

Curious wave phenomena may be noticed when a steam-boat is passing along a comparatively narrow channel. If a point is observed in advance of the boat, as a stone on a beach, or a plant on the bank, it will be seen, long before the boat arrives opposite that point, that the water recedes considerably, and that this recession increases as the boat passes it. This arises from the paddle-wheels throwing back the water, and forming a trough, or hollow, into which the water in advance of the boat rushes; and this increases with the speed at which the paddle-wheels are driven. In this way the levels of the water before and behind the steam-boat are altered, and the effort to restore horizontality may be observed in the series of large waves, which will be seen over the stern of the boat following one another at nearly equal speed. These waves, spreading, break at length against the bank, and submerge the point which had been previously dry. Where rushes grow in the water, these wave-motions are rendered very striking by the movement of the plants.

The importance of these undulations of water is very great. Did not the great ocean, by the mobility of its particles, yield to every disturbance, it would soon be rendered putrid; but these disturbances present the organic exuvia which the sea contains to the action of active chemical agencies, and thus putrescence is prevented. The influences at work on the ocean are, the attractions of the sun and moon, producing the great tidal wave; the rotation of the earth on her axis, which gives rise to a constant easterly current; the action of heat commencing those great ocean currents which flow from the warmer to the colder portions of the earth; and the winds, which, in their calmest movements, merely ripple the surface, but which, in their more violent actions, stir the ocean to a very considerable depth.

Waves of air may be regarded as presenting the same phenomena as the waves of water, modified only by the compressibility and elasticity of gaseous particles. The beautiful mathematical investigation of the laws of aerial pulsations, as carried out by Weber and Eisenlohr, are of too refined a character for a work intended to be purely elementary; the wave phenomena, therefore, which have been already described, will sufficiently answer to explain the rudimentary laws of those undulations which produce sound.

Sound originates in vibration:—a long piece of steel spring vibrates slowly, and no sound is heard; a short piece vibrates so quickly that its vibrations cannot be seen, and *sound* is the result.

The character of sound-vibrations may be rendered evident to sight by many simple contrivances; as, by a ball hung by a string to a bell,—by pieces of paper, as already described, on a violin-string,—or by sand placed on the sounding-board of a piano or any other stringed instrument. When, again, musical notes are produced by drawing the wet finger round the edge of a glass containing some water, waves will be seen undulating from the sides towards the centre.

If we strike a tuning-fork, and then touch a surface of mercury, waves will be produced corresponding to the tremor giving rise to the *tone*. If we touch a glass disc, or hold a tuning-fork over an open cylinder, or a glass which has any fine dust upon it, or water in it, we may render the vibrations very apparent; and the mode of exciting and maintaining the vibrations of a column of air may thus be shown:—Take a common tuning-fork (Fig. 126), and on one of its branches fasten, with sealing-wax, a circular disc of card of the size of a small wafer, which will cover the aperture of a pipe. If the fork be set in vibration by a blow on the unprepared branch, and the disc be held close over the

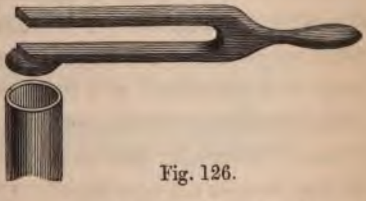


Fig. 126.

mouth of the pipe, a note of great strength and clearness will be heard. The most interesting and instructive method of studying these *sound-vibrations* is, however, by the production of acoustic figures, in the manner first devised by Chladni.

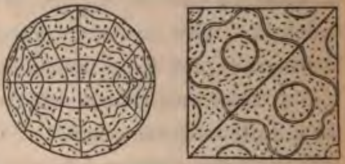


Fig. 127.

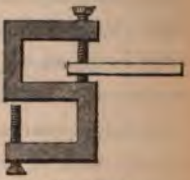


Fig. 128.

If we take square or round pieces of glass or metal, and, having strewed over the surface some fine sand or other non-adherent powder, draw the bow of a violin along its edge, various very interesting figures will be formed (Fig. 127); and by employing a clamp, as shown in Fig. 128, so as to pinch the plates in various parts, these figures may be curiously diversified. If, instead of a solid plate, we stretch a thin sheet of wet paper over the mouth of a tumbler-glass, by glueing its edges, and then, when dry, strew sand upon its surface, we may produce the same result. If, when a glass plate is vibrating, it is brought near to a glass thus prepared, the sand upon the paper will exactly imitate the motion of that upon the plate. If the glass plate, in place of vibrating horizontally, is made to vibrate in an inclined position, the lines of sand on the stretched paper will change their character with every variation in the inclination of the plate. If, when figures of one pattern are forming, we breathe over the paper, they are immediately changed. Some of these curious forms are represented in Fig. 129.

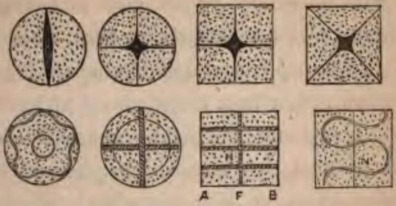


Fig. 129.

A very pleasing variation of these experiments may be made with flat glass rulers, or cylinders. By these, also, we may prove the communication of vibrations from one body to another. A long flat glass ruler is to be cemented by a little shell-lac to a tumbler-glass, and supported in a horizontal position by a piece of cork at the other end (Fig. 130). Let the tumbler be set in vibration by a bow, or a wet finger, on the side opposite to the glass ruler, it will vibrate transversely, and these motions will be communicated to the rod without any change in their direction, as will be rendered apparent by strewing sand upon the surface of the ruler, when the vibrations and the nodal lines will be well marked.

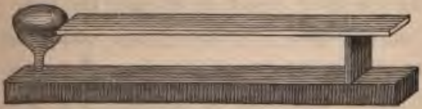


Fig. 130.

By such means as these, the undulations, which are produced by musical notes in the communicating medium —the air—may be detected at a considerable distance from a violin, pianoforte, or harp, when played.

These experimental illustrations sufficiently explain, that sound results from vibrations set up upon the membrane of the tympanum; and that the atmosphere is necessary to communicate it, may be proved by placing a bell in the receiver of an air-pump. When the glass is full of air the glass offers but little interruption to the sound, but if the air is slowly withdrawn, the ringing becomes less distinct, and eventually the clapper will be seen to strike the bell without producing any audible vibration. This arises from the absence of an elastic medium of sufficient density to convey the vibrations. If a bell is rung in a receiver of hydrogen gas, the sound of it is scarcely audible; and if we fill the lungs—by breathing—with the same gas, and attempt to speak, it will be found that the most manly voice sinks into a childish treble :—this is owing to the tenuity of the undulating medium. Similar results are obtained by ascending into the more rarefied regions of the atmosphere. Saussure relates, that when on the summit of Mont Blanc, the explosion of a pistol appeared no louder than that of a small cracker. Those who have descended in a diving-bell, must, on the contrary, have experienced the painful intensity of sound produced in a condensed volume of air. Supposing the air to be at rest, the intensity of sound diminishes in the inverse ratio of the squares of the distances of the sounding body; but, when winds are blowing from the listener to the sonorous body, this law is completely subverted.

Under some peculiar atmospheric conditions, sounds are often heard at considerable distances: the noise of cannon, it is said, has been heard at a distance of two hundred miles. It is related, that in one of Captain Parry's voyages Lieut. Foster held a conversation with a man across the harbour of Port Bowen, the distance being a mile and a quarter. On one occasion, the author of this volume, walking in the still summer twilight on the shore of the Mount's Bay, heard distinctly the conversation of two fishermen in their boat, which was at least a mile from the spot on which he was standing. The intensity of sound is varied by everything tending to alter the elasticity of the conducting medium. The wind, barometric pressure, changes in temperature, and variations in the hygometric character of the atmosphere, all produce alteration in the character of sound. Sound is heard to a greater distance over water than over land, owing to the facility with which one undulates compared with the other.

Sir John Herschel has proved that sounds of every intensity travel, when the temperature is at 62° Fahrenheit, at a rate of 1125 feet per second, or equal to 765 miles in an hour.

If standing on an eminence at some distance from a cannon which is fired, we observe the light from the explosion some time before the sound of the discharge reaches us: we may calculate the distance by noticing with accuracy how many seconds elapse between the moment the light is seen, and that at which the sound is heard. Or, we perceive a flash of lightning, and twenty seconds afterwards we hear the first burst of the thunder:—if we multiply 1125 feet, the number of feet sound traverses in a second, by 20 seconds, we have 22,500 feet as the distance of the electrical cloud from which the lightning and the thunder proceeded.

The proof of this may be always afforded by observing a man striking blows with a hammer at some distance: we shall *see* the blow struck a considerable time before we *hear* the sound of the blow.

That the intensity of sound varies with the density of the vibrating medium, is proved by experiments on the powers with which different bodies convey sonorous vibrations. Hold a watch at such a distance from a person that its ticking is not heard through the air, then place the watch and the ear of the individual at two extremities of a piece of wood of the required length, and its beating will be very distinctly heard. By the experiments of Laplace and Chladni, we have the following results of the rates at which different substances conduct sound:—

Supposing the rate of sound in

Atmospheric Air to be	1
Distilled Water will be	4·5
Saline Water	4·7
Tin	7·5
Cast Iron	10
Copper	12
Wood	15

Sound-waves are capable of reflection in the same manner as the undulations of water; and to this are due the curious phenomena of echoes. There are several very remarkable echoes in our islands; among the most striking are the following:—

An echo in Woodstock Park, Oxfordshire, repeats seventeen syllables by day and twenty by night. In Gloucester Cathedral, an echo conveys a whisper seventy-five feet across the nave. The suspension bridge across the Menai Straits repeats a blow with a hammer twenty-eight times in five seconds. On the Lakes of Killarney is a remarkably fine echo. On the north side of Shipley Church, in Sussex, an echo repeats twenty-one syllables.

The rolling of thunder has been attributed to echoes among the clouds; and if it is considered that clouds are collected masses of vapour, it will be seen that such echoes from these may prolong the sound. But Sir John Herschel suggests, that the rolling of thunder more probably arises from a succession of blows given to the air by the electric discharge, so that the ear receives a series of sounds arriving from different distances along the line of discharge.

The want of attention to the phenomena of echo and the laws of sounds, leads to most wretched arrangements in nearly all our buildings devoted either to the purposes of music or oratory.

Some pleasing effects are due to the reflection of the waves of sound from some surface at a distance from the speaker. If two reflectors are used, and if, as in the whispering gallery at St. Paul's, a person whispers in the focus of one concavity, the undulation is at once communicated to the listener in the focus of the other. By forming artificially a number of these reflecting surfaces, several repetitions of a sound may be effected, and the celebrated echo at Woodstock is due to these frequently returning waves.

It has been already explained that two aqueous undulations may destroy each other: in the same manner, two sonorous undulations may *produce silence*. That two loud sounds should be made to produce silence is among the most magical of scientific effects.

If two equal and similar strings, or equal columns of air in pipes, vibrate at the same rate, they will produce equal volumes of sound; and if the two volumes of sound are produced at the same time, they give rise to a sound double the strength of either separately: as in the case of the water-waves, the undulations coincide, and meet at the point of greatest elevation to swell into one note. Now, if we so regulate the vibrations of one, that it is not in unison with the other,—the difference, however, between them being exceedingly slight,—the quicker vibrations of one will overtake the slower vibrations of the other, and at a certain vibration, the depression of one wave is filled with the elevation of another, and no sound is heard;—*absolute silence results*, and at intervals in the vibrations the negation of sound recurs.

Musical notes are produced by regular undulations—waves following each other with perfect uniformity. *Noise* is the result of very irregular or disturbed wave-motion.

A certain number of vibrations are necessary to produce a *note*. The gravest musical sound appears to be produced by about 16, and the sharpest by 2,000 vibrations in a second; but this varies greatly with almost every ear. It is only, for example, by an effort, and when attention is directed to it, that the author can detect the chirp of the cricket. A highly sensitive ear is said to be capable of appreciating the sound produced by 24,000 vibrations in a second.

The *diatonic scale*, or *gamut*, consists of seven notes, which are distinguished by the seven first letters of the alphabet, or by the seven syllables *do, re, mi, fa, sol, la, si.* The pitch of sound depends upon the number of vibrations that the sounding body makes in a given time, and this, of course, is determined by several causes.

If a string of a pianoforte is stretched between two supports, the pitch of sound which it will produce, on being struck, varies — as it is more or less intensely stretched,—with the variations in the length of the string, —and also with the weight of the string. Indeed, everything which occasions an alteration in the number of vibrations, gives rise to a different intensity of sound.

We will suppose we have a string thirty-two inches in length, which gives a certain *key-note*. If the length of the string is reduced one-half, we then have the *octave* of that note. Between the octave and its key-note there is a natural gradation by intervals in the pitch of tone; the ascending intervals between the note and its octave being more agreeable than any other; the octave, as its name implies, being the eighth *pitch of tone*, the whole forming a complete scale of music, called the natural scale.

The length of the string producing the primary note being thirty-two inches, the lengths of the strings to produce the tones in the entire scale are—

32, 30, 27, 24, 21, 20, 18, 16.

The pitch of the different musical tones are represented to the eye by employing five parallel lines, called a staff, or stave, the degree of pitch being shown by characters placed upon those lines or on the spaces between them, as in Fig. 131, these characters being called *notes*; the whole in this example representing one octave and part of another.

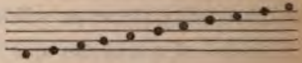


Fig. 131.

If the notes combining with another note—which we will call c—to make an agreeable impression on the ear, be examined, they will be found to be those which stand in a certain relation to c, in the rapidity of their oscillations; their wave lengths being $\frac{1}{2}$, $\frac{2}{3}$, $\frac{3}{4}$, $\frac{5}{6}$ of the length of the wave c.

In stretched strings the following laws prevail:—

1. The number of vibrations of a string is inversely as its length.

2. The number of the vibrations of a string is proportional to the square root of the stretching force.

3. The number of vibrations of different strings of the same substance is inversely as their thickness.

The vibrations of a column of air in a pipe may be regarded as obeying the same general laws: notes are naturally higher in proportion to the shortness of the pipes. The air-waves impelled through the Pandean pipes, the pipes of an organ, a flute, a clarionet, or a trumpet, impart corresponding vibrations to the sounding material, and hence the difference in the tones and intensity of different instruments. That musical notes are thus produced in solid masses is proved by placing a bar of metal, which has been heated, to cool, with one end supported upon a wedge-shaped piece of metal, of another kind, as in Fig. 132;—a piece of iron, for example, upon a piece of lead. Musical sounds, similar to the tremulous notes of an Æolian harp, are produced under these conditions, and they will be found to vary under almost every change of the circumstances. These tones are due to the molecular disturbance producing very rapid pulsations, in a regular series, along the bar.

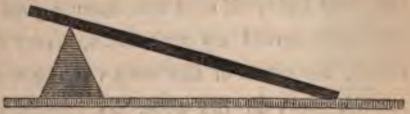


Fig. 132.

Musical notes may also be produced by placing a long bar of metal within a helix of copper wire, resting its extremities upon some fine edge of a non-sonorous body, and then, by connecting the wire with a galvanic battery, producing an electrical disturbance along the wire:—every time connection is made or broken, a distinct musical note is distinctly heard. The chemical harmonicon is an interesting exemplification of another of these wave phenomena. The best mode of safely trying the experiment is as follows:—Take a large bottle, and fit into the cork of it a tube which has a very fine orifice. Place some granulated zinc in the bottle, and pour upon the metal some very diluted sulphuric acid, and insert the cork. Hydrogen gas is thus formed, which will issue from the jet with some degree of force. Allow the gas to escape for a few minutes, that the atmospheric air which was in the bottle may be got rid of, and then ignite the jet of gas issuing out, which will burn with a small blue flame, giving but little light. If over this flame a glass tube is held, and gradually moved up and down, a very clear note is produced, the pitch of the note varying with the thickness of the glass in the tube, its length, and many other causes. The musical notes are produced in this instance by a rapid succession of small explosions, as the hydrogen gas mixes with common air in the tube.

The organs of speech present to us an exceedingly beautiful contrivance, adapted for the production of every variety of sound. They consist of the *windpipe*, a tube extending from one extremity of the throat to the other ending in the lungs, through which the air passes to and from these organs of respiration; the *larynx*, formed of four cartilages, the cricoid, the thyroid, and two arytenoid—these are moved and varied by means of different sets of muscles; the *glottis*, formed principally by the *chordæ vocales*, which are merely a very elastic tissue; and the *ventriculi Morgagni*, which form a sort of second glottis. The following figures show the formation of the larynx:—the first represents an anterior, the second a lateral, the third a posterior, and the fourth a superior view of this organ.

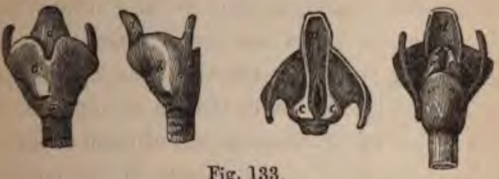


Fig. 133.

The formation of notes in the larynx is precisely similar to that of reed-pipes, as may be illustrated by the following arrangement:—Take a piece of sheet India-rubber, and fold it around a glass cylinder, as in Fig. 134; then, by warming the two edges, they may be easily united, and form an external cylinder of caoutchouc. This represents the mouth: and by blowing into the glass cylinder, and stretching out the India-rubber, so as to imitate the action of the lips, a great variety of tones may be produced.

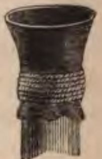


Fig. 134.

A curious pipe is employed in the Organ to imitate the human voice (Fig. 135). It is composed of a very short conical tube, the base upwards surmounted by a short cylinder, and the pitch is regulated entirely by the reed. There is a circular operculum which half closes the open

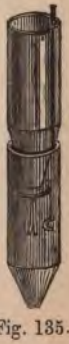


Fig. 135.

end of the cylinder, to imitate the lips; the reed performing the part of the larynx, and the pipe itself of the cavity of the throat and mouth.

Fig. 136 represents the so-called chimney-pipes of the same instrument, which are closed at the upper end by covers, through the centre of which passes a pipe of small diameter, as a continuation to the lower one; these produce sounds intermediate between the tones of open and stopped pipes. The construction of them is given, as showing a very simple form of pipe by which, with the one previously drawn, a great variety of interesting experiments may be made.

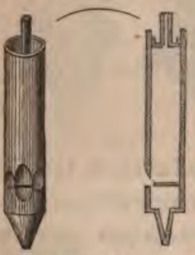


Fig. 136.

Such are the principal phenomena which belong to the interesting subject of sonorous wave-vibration.

CHAPTER VI.

PRIMARY PHENOMENA OF ELECTRICITY.

ELECTRICITY,—from ηλεκτρον, *electron*, amber;—Thales of Miletus having first observed a peculiar attractive and repulsive power in that substance, which was eventually proved to be due to a subtile principle, supposed to pervade all nature, and which certainly is one of the most important of the great physical agents.

Some of the peculiar phenomena of electricity are very easily rendered evident:—Take a stick of sealing-wax, and after having rubbed it freely upon a coat-sleeve, or with a piece of woollen or silk, pass it an inch or two above small fragments of paper or metal leaf, when they will be forcibly attracted, and cling to it.

Or, take a sheet of ordinary writing-paper, and having dried it by the fire, place it upon a dry painted table-cover, and rub it smartly with a piece of India-rubber. On attempting to lift up the paper from the table by one corner, it will be found to adhere with some force to the cloth; when we hold it in the air, and present the knuckle to it, if in a dark room, a little spark of brilliant light will be seen to pass from the paper, and at the same time a small sharp crack may be distinguished.

If a dry glass tube is taken, and rubbed freely from end to end with a warm silk handkerchief, in the dark, small streams of light will be seen, a crackling noise heard, we shall become sensible of a remarkable smell, and, if the tube is held near the face, a peculiar creeping sensation will be felt.

Gutta percha has very peculiar electrical properties. These are shown in a striking manner, if we take a dry piece of this substance rolled into a thin sheet, and, in a dark room, strike the fingers briskly over its surface;—sparks, flashes, and luminous streams will be seen to follow them, and a crackling noise will be distinctly heard.

By suspending from any convenient support a light body, as a ball made from the pith of the elder, we may examine a little more closely the peculiar conditions of attraction and repulsion. If towards a ball thus suspended we bring a glass rod, excited, as before described, by rubbing, it will be attracted towards and adhere to the tube. After a short time the ball will fall off from the glass, and be repelled by it as forcibly as it was previously attracted, nor will it be again attracted until it has touched some body in contact with the earth, and thus re-acquired the property it has lost. If, while this repulsive force is being exerted, a piece of sealing-wax excited by rubbing is brought near the ball, it will be immediately attracted; having clung for a few seconds to the sealing-wax, it will leave it, and rush towards the glass tube, and in a short time quitting the glass, it will pass over again to the resin. Thus, if the sealing-wax and the glass tube are placed sufficiently near, the ball will continue to pendulate between them.

The cause which gives rise to these curious phenomena is unknown to us. We are enabled to examine a great variety of effects, but the agency to which these are due does not appear to be within reach of human intelligence. Various theories have been, from time to time, propounded, having different degrees of value, as enabling us to account for many of the phenomena, the most important being the following.—

Newton thought that electric bodies, when excited, emitted, in consequence of the disturbance of their molecular arrangement, a very attenuated fluid.

The theory of Fay and Symmer supposed an exceedingly thin and subtile fluid pervading the most compact bodies, which was a compound of two ultimate elements, distinguished by them into *vitreous* electricity, or that given off from glass, and *resinous*, or such as we find developed upon rubbing a stick of sealing-wax. Each kind of electricity was supposed to repel its own particles, but to attract the particles of the other kind. When these primary electric elements are disunited, they manifest their powers energetically in endeavouring to restore an equilibrium. Now, if we suppose vitreous electricity to be in excess, or rendered active, it tends to disturb the dormant electricity of the other kind, and a neutral body is thus excited, or an electrical disturbance is *induced*,—this constituting what is called *induction*. It will be evident, upon consideration, that *attraction* is the consequence of this; the opposite electricities endeavour to combine, and excited bodies free to move attract each other: *repulsion* being supposed to spring from an excess of one kind of electricity in the repellent substances;—this, however, appears to be the weak part of this theory.

The *Franklinian* theory, so called from its having originated with the celebrated Dr. Franklin, supposes the existence of a single imponderable highly subtile and elastic fluid, equally distributed throughout nature; every substance, organic or inorganic, being constituted to retain a given quantity of this agent, as being necessary to its physical condition, but when in repose offering no evidence of the electrical presence. Any disturbance of the natural state of a body produces evidences of electricity; electrical *excitation* being supposed to arise from the difference in the relative quantities of this principle existing in the electric and the rubber, or in their powers of receiving and retaining electricity. Thus, one body becomes overcharged by having abstracted this principle from the other. These conditions are called *plus* and *minus*, or we say one body is *positive*, and the other *negative*. There being a constant tendency of the electric fluid to an equilibrium of distribution, a body which contains an excess, endeavours to throw off, or communicate, a portion of its excess to a neighbouring body which contains less, and thus produce an equalization. This is the cause of *induction*, upon the Franklinic theory. *Attraction* is considered, as in the previous theory, to be the immediate consequence of induction; bodies in opposite states inducing a flow of the electric fluid (this term is employed merely because it is a familiar one) from one to the other, and consequently manifesting an attractive power. *Repulsion* is supposed to be the result of the action of two or more bodies overcharged and parting with their electricity: but this view is not very satisfactory.

Dr. Faraday, whose experimental researches in electricity far exceed in number and completeness those of any other man, is rather disposed to regard this agency as "a mere power of matter, like what we conceive of the attraction of gravitation." It is not easy to make this view clearly intelligible to such minds as have not been accustomed to metaphysical studies; it is hoped, however, that the following statement will be sufficiently comprehensive. Every atom of matter is regarded as existing by virtue of certain properties or powers, these being merely peculiar *affections*, which may be regarded as being of a similar nature to vibrations. It is assumed that the electric state is but a *mode* or *form* of one of these affections. One particle of matter, having received this form of disturbance, communicates it to all *contiguous particles*,—that is, those which are next to it, although not in contact,—and this communication of force takes place more or less readily, the communicating particles assuming a polarized state,—which may be explained as a state presenting two dissimilar extremities. When the communication is slow, the polarized state is highest, and the body is said to be an *insulator: insulation* being the result. If the particles communicate their condition readily, they are termed *conductors: conduction* is the result. The phenomena of *induction*, or the production of like effects in contiguous bodies, is therefore, according to this view, but something analogous to the communication of tremors or vibrations.

Either of the preceding hypotheses—of two electricities, or of one,—may be adopted in connection with the views of this philosopher; it will, however, be evident to all, that I am not disposed to entertain this view, but rather to consider, with Franklin, that electricity has a positive entity; that it is a subtile body condensed on the surfaces and through the pores of all bodies in virtue of some of the forces of matter which have been already considered.

Leaving these considerations with this brief notice, it will be interesting to convey some idea of the quantity of electricity in nature. We owe the knowledge of the enormous amount of this agent in producing the physical conditions of matter as it now exists, to Dr. Faraday. This able investigator of nature has shown that the absolute quantity of electric power belonging to different bodies, may be determined by ascertaining the amount necessary to break up their chemical affinity; the law being most satisfactorily established, that *the electricity which decomposes, and that which is evolved by the decomposition of, a certain quantity of matter, are alike.*—

"*One grain* of water, acidulated to facilitate conduction, will require an electric current to be continued for three minutes and three quarters of time, to effect its decomposition, which current must be powerful enough to retain a platina wire of $\frac{1}{104}$ of an inch in thickness (its length being a matter of indifference) red hot in the air during the whole time, and, if interrupted anywhere by charcoal points, will produce a very brilliant and constant star of light. It will not be too much to say that this necessary quantity of electricity is equal to a very powerful flash of lightning. Yet we have it under perfect command; can evolve, direct, and employ it at pleasure, and when it has performed its full work of electrolyzation, it has only separated the elements of a single grain of water."

To give a more complete idea of this quantity,—Dr. Faraday continues,—a certain electro-chemical arrangement produced "as much electricity in little more than three seconds of time, as a Leyden battery, charged by thirty turns of a very large and powerful plate electric machine in full action. This quantity, though sufficient, if passed at once through the head of a rat or a cat, to have killed it as by a flash of lightning, was evolved by the mutual action of so small a portion of the zinc wire and water in contact with it, that the loss of weight sustained by either would be inappreciable by our most delicate instruments. It would appear that 800,000 such charges of the Leyden battery as I have referred to above, would be necessary to supply electricity sufficient to decompose a single grain of water."

From these remarkable evidences, the result of most accurate experiments, it is rendered certain that the absolute quantity of electricity existing in all the various forms of gaseous, liquid, and solid matter, must be so immense, as to be beyond the comprehension of our limited intelligences.

Before proceeding with any closer examination of the laws which regulate electrical phenomena, it is important that we should become acquainted with the various instruments employed in such researches, and establish the meaning which it is desired should be attached to the terms employed.

Numerous contrivances have been, from time to time, introduced, for exhibiting the attractive and repulsive agency of electricity, and readily obtaining indications of its presence. Instruments of this description are called *electroscopes.*

One of the most simple consists of a slight metalilc needle (Fig. 137), terminating at each extremity in a light pith ball, covered with gold leaf: this needle, having a cap at its centre, is fixed upon a fine steel point, so that it moves with great freedom. Any excited body presented to either of these balls will attract or repel the needle. Sometimes a pair of pith balls are suspended from a brass ball, fixed to a glass handle, by very fine threads. Cavallo contrived an electroscope of this kind, which is exceedingly convenient. Two fine silver wires, each of them having a pith ball at one end, are fixed to a long varnished cork, which fits either way into a glass tube (Fig. 138). When the instrument is not required for use, the wire and pith balls are placed in the tube, as seen at *a*, and from its portability in this condition, it can be carried in the pocket. When it is employed as an electroscope, the wires are taken out, and the cork reversed, as at *b*. In this condition the tube serves as a glass handle, and upon bringing any electrified body near the balls, their sudden divergence will indicate the degree of excitation.

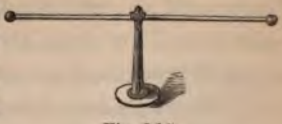


Fig. 137.

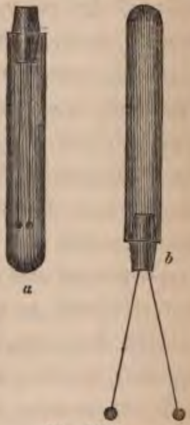


Fig. 138.

Leaf gold and silver, and the beaten brass, known as Dutch metal, are very commonly employed to indicate very small quantities of electricity. All the metal-leaf electroscopes are constructed in a very simple method:—the single leaf, or the two pieces of leaf, being suspended in a glass vessel to protect it from currents of air, are connected with a brass cap or ball, which is adopted for communicating the electrical influence of any body under examination.

To understand the effects, take a few pieces of gold or silver leaf, and attach them to pieces of glass rod, or even rolls of dry paper, these being intended to serve as handles merely. Rub a piece of sealing-wax, or glass, or brimstone with a woollen cloth, and presenting the excited body to one of the gold-leaf electroscopes thus prepared, it will be either attracted or repelled,—it has itself partaken of the peculiar electric condition. Bring a second piece of gold-leaf into the same state, approach two pieces towards each other, and, being similarly electrified, they will *repel each other*. If, on the contrary, one gold-leaf is excited by a resinous body, and the other by a vitreous substance, it will be found, on bringing them together, that they *attract each other*.

It will be seen, after a few experiments of this class, how very readily delicate electroscopes may be made. For example, a glass cylinder is obtained, it is fitted into a bottom of dried and varnished wood; two pieces of gold-leaf, about three or four inches long and one inch wide (*g*, Fig. 139), are fixed to a projecting piece of brass connected with a disc of the same metal, which will form the top of the cylinder *s*, and which is cemented to the glass. When any excited substance is brought in contact with the brass cap, this metal, being a good conductor, carries the electricity to the gold leaves, *g*, and they are repelled. The annexed figure, to which we have been referring, is usually called Bennet's gold-leaf electrometer, and it only differs from the above description in having two slips of tin-foil, *s* and *t*, pasted to the inside of the cylinder. The object of this is to carry off from the gold leaves the accumulated electricity, when the divergence is sufficiently great to drive them against the sides: these slips of tin-foil are connected with the bottom of the instrument, and serve to convey the electricity to the earth. All instruments of this class indicate merely the presence of an electrically excited body; they do not measure the quantity, either relatively or absolutely, of the electricity in action.

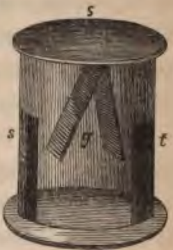


Fig. 139.

The most simple form of *electrometer* is shown in Fig. 140: *q* is a semicircle of varnished paper or ivory, which should be graduated, fixed upon a firm vertical rod, *s*; *r* is a light reed, or slip of baked and varnished wood, suspended by a pin from the centre of the semicircle, and terminating

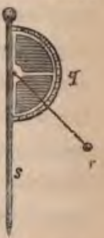


Fig. 140.

in a pith ball. The number of degrees through which the ball is attracted or repelled by any body brought near to it, indicates approximately the active quantity of electricity. No very accurate result can be obtained with even this electrometer; therefore, in refined researches, instruments of greater delicacy, and of more ingenious construction, must be used. The electrometer usually employed for measuring with great accuracy small quantities of electricity, is that of Coulomb, which has been called by its inventor the *torsion balance*. Since an instrument of this description would only be found in the hands of very advanced students, a mere general account of its principle will be sufficient in this treatise. If a silver wire is slightly twisted, a certain force is exerted to overcome this, and return the wire to its original condition; and Coulomb proved that the tendency of a twisted wire to return to its previous position is exactly proportionate to its angle of *torsion*, or twist. By an ingenious though simple contrivance, a gilded pith ball on a stick of shell-lac, which is hung, balanced, by a silver wire, is electrified by induction, and by the repellent force the wire is twisted. Now, the force of torsion being known, and the angle of divergence being marked by a carefully graduated circle, it will not be difficult to see that the two forces—the mechanical and the electrical,—balanced against each other, may be made a very delicate measurer of the relative quantities or force of the excited electricity.

The hydrostatic electrometer of Sir William S. Harris is a very beautiful instrument, but from the advanced knowledge necessary before it could be usefully employed, any description of it is omitted. Those, however, who desire to make themselves acquainted with it will find it most fully described in the Philosophical Transactions for 1839.

Such bodies as acquire electricity by friction, are usually called, to distinguish them, *idio-electrics*, while those which do not possess this property are termed *anelectrics*.

Faraday employs the terms *electric* and *dielectric* ;—the first signifying all those bodies which, not being conductors of electricity, allow it to accumulate upon their surfaces, and to be thus rendered evident by certain results; the second to express that substance through or across which the electric forces are acting. Conductors, or those substances which admit of the free passage of this principle, *cannot be bodily charged.*

ELECTRICS are of the following character:—Amber, sulphur, bitumens, and all the resins; wax and gums, particularly camphor; caoutchouc and gutta percha; glass, all vitrified bodies, and porcelain; the diamond, agate, tourmaline, and most siliceous gems and stones; silk, dried animal furs and skins, hair, wool, feathers, and paper; turpentine, oils, and fat acids; all dry gases, highly elastic steam, and ice at the zero of Fahrenheit.

ELECTRIC CONDUCTORS, or *anelectrics*, are metals of every kind, differing only in degree; charcoal and plumbago;

concentrated and diluted acids, and water; vegetable matter, both living and dead, if moist, and living animal matter; flame, smoke, and ordinary steam. All electric bodies are non-conductors, or insulators: a substance placed upon them, not being able to part with its electricity as readily as it receives it, becomes *charged*. The best *insulating* substances are glass, shell-lac, gutta percha, and sulphur.

The experimental researches of Faraday prove, however, that there are no perfectly insulating bodies, or any which perfectly conduct. Insulation and conducting power are only differences in degree;—metals and acids, and the moist soil of the earth, standing at the head of the list of electrical conductors; the substances constituting the rocky crust of our planet, occupying the intermediate position; and brimstone, resin, glass, and gutta percha being at the bottom of the list.

For the purpose of aiding inquiry into the wonderful properties of this peculiar agent, it became necessary to devise means by which large quantities of electricity could be evolved and collected. The first idea of an electrical machine is due to the philosophical inventor of the Magdeburg hemispheres, the Burgomaster Otto von Guericke, who mounted a globe of sulphur upon an axis, and causing it to revolve and rub against the hand, he thus obtained a very considerable amount of electrical excitation. Numerous varieties of machines have been constructed; but as those in which glass is the electric, are now the only kind employed, our description must be confined to this variety.

The glass cylinder machine (Fig. 141) is of very simple construction. A hollow glass, with open ends, for the convenience of fixing it firmly on its axis, is mounted on glass pillars (to ensure insulation), in such a manner that it can be rapidly turned by the handle connected with its axis. A rubber of oiled silk, being a cushion stuffed with wool or hair, is attached to a bar fixed horizontally to a vertical glass pillar; to this cushion is fastened a flap of silk, sufficiently large to cover one half of the glass cylinder: by means of a screw this cushion is made to press uniformly against the glass. On the opposite side, directly where the silk flap terminates, is fixed another horizontal bar, of brass, carrying a series of points, which, being opposite the glass, receive and collect the electricity produced by the friction of the silk upon the glass. This brass bar is usually a hollow cylinder of that metal, and a large brass ball is screwed on it:—this is the prime conductor. A similar bar is employed to collect the negative electricity from the insulated rubber, when this is desired.

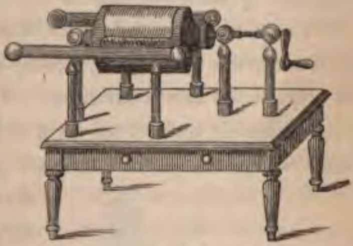


Fig. 141.

In 1766 a circular disc of shell-lac was employed by

Van Marum, which gave rise to the use of glass plates. In 1785 Van Marum, assisted by Mr. Cuthbertson, constructed a machine, which had two glass plates, each of them 65 inches in diameter. This electrical machine was set in motion by four men; and it is stated that the spark from it would melt a leaf of gold,—that a thread was attracted at the distance of 38 feet,—and a pointed wire exhibited a luminous star at the distance of nearly 30 feet from the prime conductor. Since that time this form of the machine has been generally employed, as being in all respects the most convenient. This electrical machine will be readily understood by a brief description of the annexed figure. A circular glass plate is mounted upon a metallic axis, and supported upon pillars, fixed to a secure base, so that the plate can, by means of a handle, be turned with ease. Upon the supports of the glass, and fixed so as to press easily but uniformly on the plate, are four rubbers; and flaps of silk, oiled on one side, are attached to these, and secured to fixed supports by several silk cords. When the machine is put in motion, these flaps of silk are drawn tightly against the glass, and thus the friction is increased, and the electricity

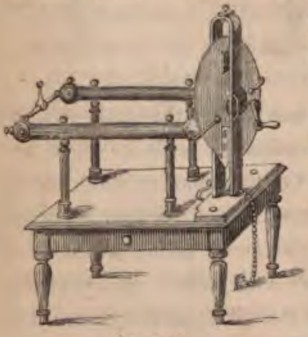


Fig. 142.

excited conveyed to the prime conductor. The prime conductor consists of a curved arm of hollow brass, or two straight brass cylinders, connected by another cylinder. There is more difficulty in obtaining negative electricity from the plate machine than from the cylindrical one, because of the rubbers being uninsulated.

Experiment has proved that an amalgam of quicksilver, tin, and zinc, mixed with a little lard, and placed on the rubbers of any form of glass electrical machine, increases considerably the quantity of electricity evolved. This would appear to be due to some chemical action, or probably it may be that it merely effects a more perfect contact between the surfaces. The proportions which answer best, are eight parts of mercury, six parts of zinc, and four of tin. The zinc and tin are melted together in an iron vessel, and being poured into a box, the mercury is to be added, the cover put on, and all shaken together, until the amalgam is cool. After this it is triturated in a Wedgewood mortar, and a sufficient quantity of grease added to give a stiff coherency to the granulated mass.

The evolution of electricity from the glass, and its development upon the prime conductor, is a phenomenon of induction. The attrition between the rubbers and the glass produces a molecular disturbance, and thence arises an electrical disturbance, which by induction is communicated to the metal of the conductor, which, from its nature, forms a free channel, through which it is conveyed to any other body, or discharged into the air. If the rubber is insulated, after a slight excitement no more electricity can be obtained;—it would appear as if the source was exhausted; but if any connection is made with the earth, the electrical manifestations can be sustained for any period.

One theoretical explanation given is, that the compound electricity in the rubber is decomposed, that its positive electricity adheres to the glass, while the glass, from the attractive power of the two electricities, robs the prime conductor of its negative electricity, leaving free positive electricity in active excitement on the metal of its surface. This explanation appears, however, to be open to very serious objections. It appears to the author that a large amount of confusion has been created by the different meanings which have been given to *positive* and *negative* electricity, and it is necessary that some well-defined idea should be attached to these terms. In the difficulty by which the entire question is surrounded, the most consistent course is to adopt that theory which explains in the simplest form the largest number of facts, and beyond all question the Franklinic theory meets those conditions. One electric agent—and one only—is diffused through all nature, the quantity varying with the physical condition of the body; this subtile principle, being excited, has a tendency to diffuse itself to other bodies contiguous to the excited or electrified body. The electricity flowing out of any substance—if it be allowable to speak of a disturbance as flowing—is in the *positive* state; a body receiving, owing to its having lost its natural volume of electricity, this principle from a contiguous body, in the effort which is ever made to equalize the distribution, exhibits *negative* electricity, or electricity flowing in.

A substance parting with electricity exhibits the positive flash or spark; a substance absorbing electricity manifests to our senses the negative brush or glow. In the annexed wood-cuts (Figs. 143 & 144) are represented the more striking peculiarities of the *flash*, the *spark*, the *brush*, and the *glow*.

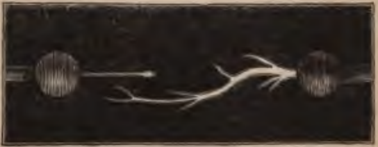


Fig. 143.

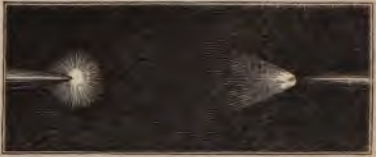


Fig. 144.

Volta devised a very simple machine, which is known by the name of the *electrophorus*, or bearer off of electricity. It is easily constructed. Melt some shell-lac, and pour it into a plate: when cold we obtain a circular disc of this resin. This is placed upon a metal disc of the same size, and by a rim secured to it,—this is termed the *sole*; another metal disc, called the *cover*, is obtained, and into this is fitted a glass handle. To use this machine, the cover is removed by its insulating handle, and the resinous plate is excited by rubbing it with dry silk or hare-skin, after which the cover is replaced. This conducting body is now in precisely the same condition as the prime conductor of a cylindrical electrical machine; it is charged, and ready to part with its electricity to any body brought near it.

Another form of machine is the hydro-electric machine, which is of recent date, although the phenomena on which its construction depended have been long observed by working engineers. When they have been blowing off steam at night, and the air has been in a very dry state, it has not been at all uncommon for the men, adopting their own expression, to "see the steam on fire."

Attention was, however, particularly directed to the circumstance in 1840, by a workman on one of the northern railways observing an electric spark whenever he brought his hand towards the boiler of a locomotive engine, which had been accidentally insulated. Mr. Armstrong, a scientific engineer, proceeded to investigate the circumstance, and with an insulated brass rod, having a metallic plate at one end and a ball at the other, he succeeded in obtaining seventy sparks per minute, the plate being placed in the issuing steam, and the ball brought near the boiler. Following up the investigation, Mr. Armstrong succeeded in constructing hydro-electric machines, capable of exhibiting very striking phenomena.

By insulating a small steam-boiler on glass legs, and by cutting off metallic connection with the chimney, we obtain the primary condition required, and under these circumstances electricity may be detected when steam is issuing from the safety-valves.

Faraday has shown that the issue of *steam alone* is not sufficient to evolve electricity; the presence of water is necessary, and when perfectly dry steam is made to escape, there is no electrical manifestation. The moment, however, the steam begins to condense, a powerful evolution of electricity takes place. From a very complete set of researches by Armstrong, Faraday, and Schafhaeutl, it was proved that, to produce great effects, the steam charged with water must be made to rub against some non-conducting substance. Hence the steam from the boiler escapes into a chest, from which proceed several tubes, shaped as in Fig. 145, the mouths of the jets being formed of hard wood. The whole effect depends upon the friction of *pure water* upon the wooden mouth-piece, the watery particles performing the office of the glass plate, the jets the part of the rubber.

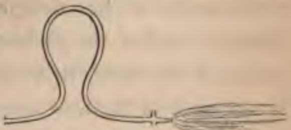


Fig. 145.

Faraday found that the common water, such as is supplied to London, gave no electricity. From distilled water it was abundantly evolved; but upon adding a small crystal of sulphate of soda, of common salt, of nitre, or the smallest drop of sulphuric acid to the water, the apparatus was utterly ineffective, and no electricity could be produced. This effect is due to the circumstance that the salts and acid render the water a good conductor, so that the electricity produced is immediately carried off.

The effects of different substances employed at the point of efflux, and also combined with the water, were carefully studied by Dr. Faraday, and also those produced by the friction of compressed air. *Dry air* was found incapable of exciting electricity, but *moist air* occasioned it to be evolved as with steam and water. The result of this inductive analysis of the question was the full determination of the fact, that in the hydro-electric machine the electricity is the consequence of the violent attrition of watery particles against a non-conducting substance.

The other sources of electricity will find a place in our consideration of the electricity of contact, or chemical electricity, and of the phenomena of magnetism.

One of the most striking effects of electricity is the development of light, of a peculiarly beautiful character, whenever it has to pass from one good conductor to another through a resisting medium. Fig. 146 represents a very pleasing arrangement for exhibiting the phenomena of this form of electric light. Upon a plate of glass are placed, at a short distance from each other, any number of circular or angular pieces of tin-foil. When the metal at either end is connected with the prime

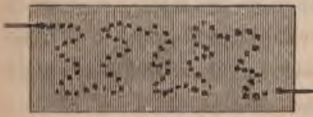


Fig. 146.

conductor of an electrifying machine, the sparks pass from one piece of tin-foil to the other, forming a stream of beautiful light. Any device may be adopted, according to the fancy of the constructor.

It is desirable in many experiments to obtain an accumulation of electrical power, and about the middle of the last century some philosophers of Leyden devised the means of doing this. They enclosed a conductor, water, in a non-conductor, glass,—and communicated the electricity to the liquid, by carrying a nail into it, which was connected with the prime conductor of the machine. An arrangement of this kind having been made, an experimenter, when endeavouring to remove the nail from the bottle, received a severe electric shock. All the early statements of the electric shock are greatly exaggerated, but the effects were of a sufficiently striking character to attract the attention of all the electricians of Europe. Muschenbroek of Leyden is usually regarded as the inventor of the Leyden jar, but he does not appear to have been the first who discovered the effect of thus combining a good and bad conductor, and he certainly did not perfect the instrument. Sir William Watson, Smeaton, and Canton divide the merit of perfecting the Leyden jar, which is one of the most important arrangements to be found in the range of electrical science.

The Leyden phial, or electrical jar (Fig. 147), consists of a bottle, having a wide mouth, coated within and without, to the line *a b*, with tin-foil; a metallic wire, with a knob at one end, is passed through a cover, and connected with the interior metal, either by a chain, or by being cemented directly to it. The Franklinic plate is well adapted to explain the phenomena of the Leyden jar, and for the examination of the question of the combined or single electrical theory. It consists of a glass plate, about one foot square, the middle of the glass on either side being covered with tin-foil, leaving about three or four inches of free margin. To ensure perfect insulation, the glass is varnished over all its uncovered parts. This plate differs from the jar in scarcely any particular, and by a piece of wire the passage of the excitement from the metal plate on one side to that on the other is familiarly shown.

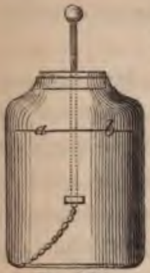


Fig. 147.

The knob of the rod of the jar being brought into contact with an excited electrical machine, the interior metal is *charged*,—it has electricity in excess:—owing to the imperfect conducting power of glass, none can pass over to the metal on the outside, and that is consequently, in relation to the interior, in a *minus* state; hence the use of the terms *plus* and *minus* by one school of electricians. If, now, any communication is made between the interior coating and the exterior coating through a good conductor, as a metal wire, a rush immediately takes place to restore the equilibrium—a discharge ensues. If an individual holding a wire in each hand, touches with one piece the knob of the jar, and with the other the exterior coating, the equilibrium is established, by the surplus charge passing through his body, and he receives a violent shock—the man has been electrified. By accumulating a great many of these jars together, and properly connecting them, almost any amount of electrical power can be obtained, and the result of the discharge would be most destructive. We may, by such arrangements, produce the effects which we see manifested in a thunder-storm; the flash of the lightning and the crack of the thunder (of course without its prolonged roar) are to be faithfully represented, with that difference in degree which is well expressed in the words of the Abbé Nollet, who says, "thunder and lightning being in the hands of Nature what electricity is in ours."

If gold and silver wires are placed on paper, so that the discharge of a powerful battery is passed through them, they are deflagrated, and their oxides remain upon its surface;—many other metals may be employed. In these experiments it is necessary to use an electrical discharger, which consists of a brass wire, with a knob at each end, bent as in Fig. 148, fitted into a glass handle. For passing a charge through bodies which we desire to decompose or deflagrate, an ingenious apparatus, called the universal discharger, is employed. It consists

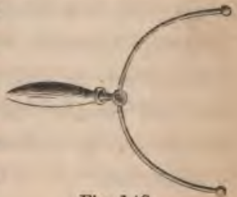


Fig. 148.

of two brass wires, fixed with a cradle or ball and socket joint (Fig. 149) on the top of glass supports; these wires are moveable in any direction. In a hollow wooden support moves a table, between them, in which is placed a piece of ivory, for the purpose of holding any substance which is to be submitted to the action of the battery discharge. The wires are brought in contact with the excited Leyden jar, or series of jars, and the whole force is passed from one point across the table to the other.

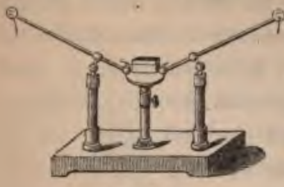


Fig. 149.

It must always be remembered that in all electrical phenomena, the establishment of a circuit, through which the equilibrium of forces can be effected, is required: this may be accomplished through either good conductors or imperfect ones; but in every instance it will be discovered, upon close examination, that as electricity has been evolved at one point, it is returned at another.

Having described the various machines by which electricity may be produced in very large quantities, we must now consider the other sources from which this principle may be evolved, or the means by which it may be manifested.

In most of the following experiments the gold-leaf electrometer is necessary, and the best form of it for those investigations is that represented in Fig. 150. Melt some sulphur and pour it into a dry wine-glass; place a glass rod in the mass while fluid; when cold, remove it by the glass handle, and place it on the table of the electroscope; the leaves, by their divergence, will show the excitement of the sulphur. Warm a piece of tourmaline, and place it on the top of the electroscope to cool; it will, in cooling, give evidence of strong electrical action. If we place some gun-cotton on the top of the electroscope, and then gently pull its fibres apart, the gold leaves will diverge. If the gun-cotton dissolved in ether—collodion—is allowed to evaporate, a very fine skin forms, which is an extraordinary electric, the smallest amount of friction giving rise to intense excitement.

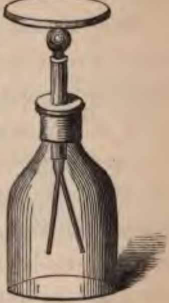


Fig. 150.

By chemical action we may exhibit similar phenomena. Place a bottle on the top of the electroscope, and, having put some iron filings into it, pour thereon some dilute sulphuric acid: during the chemical action much electrical excitation will be evident. White and black ribbon, being pressed together with a small amount of friction, as by drawing them between the finger and thumb, adhere; but in this state they exhibit no other electrical change; separate them by pulling the pieces asunder, and on approaching the gold-leaf instrument, the leaves will immediately diverge. Laminæ of mica and some other minerals exhibit much electrical excitement when suddenly rended.

Mere contact of dissimilar bodies will produce electrical disturbance. If the metallic condenser, which is fixed on the top of the electroscope, is of brass, and a plate of zinc is pressed closely upon it, we shall perceive, on removing the zinc, a divergence of the gold leaves. If we place in a glass tube a series of discs of silvered paper and zinc in this order—S.P.Z., S.P.Z., S.P.Z., S.P.Z.,—so that we have silver at one end of a long series, say a thousand, and zinc at the other, we have, by the mere association of these groups in consecutive order, produced an *electric column*, or the dry pile of Zamboni, which will exhibit all the phenomena of positive and negative electricity. It may, indeed, be safely affirmed, that every change or disturbance, whether produced by heat, by mechanical force, by chemical action, or any other means through which the molecular arrangement of any surface is, in the slightest degree, physically altered, always gives rise to electricity.

Electrical experiments are amongst the most striking which can be exhibited; but in this volume it is intended to deal with those alone which illustrate any striking facts. The attraction and repulsion of light bodies has been already named; the philosophical instrument makers are, however, in the habit of preparing figures made of the pith of elder, which by the following arrangement may be made to move, often in a very animated and grotesque manner. Hang from the brass ball of the prime conductor of an electrical machine, a copper disc (Fig. 151), and about three inches below it place another, somewhat larger. On exciting the machine, the upper plate is by induction brought to a positive state, while the lower plate is in a negative condition. Any light figures placed between these discs are alternately attracted and repelled, the equilibrium being restored through them.

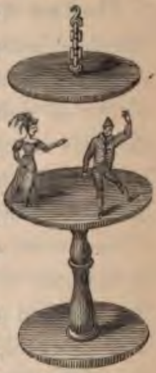


Fig. 151.

A curious and easy example of electrical repulsion, from bodies similarly excited, may be obtained by tying a bundle of threads at both ends, and hanging them to the prime conductor: on turning the machine they are all equally brought to the same condition, and, repelling each other, they spread out into a spheroid, retaining that form so long as the machine is kept in action.

Motions are produced by electricity. If a curved metal rod is placed on a point in connection with the prime conductor, so that it will turn freely, it will, when the machine is put in motion, begin to rotate, and, in the dark, brushes of light will be seen to flow from the points. In this little apparatus the effects are analogous to those already described in the flow of water from the waterwheel of Whitelaw (page 128). If four pointed wires are employed, they rotate, forming in the dark a ring of electric light.

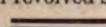
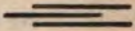
The force of an electric discharge is well shown by the following method:—Take a phial, fill it with olive-oil, and pass through the cork a copper wire, bent near the bottom at right angles, so that its point presses against the glass on the inside. This phial, thus arranged, is to be hung to the prime conductor, and, on exciting the machine, the wire becomes positively electric, a high state of tension being induced. Present the knuckle opposite to the point of the wire, bright sparks will pass through the glass and perforate a hole. If discharges are passed through a card, holes are pierced in a similar manner, and these holes have a remarkable character—a *burr*, or ridge, is formed on either side, showing that a disruption has taken place equally in each direction.

Electrical discharges are usually divided into the *conductive*, the *disruptive*, and the *convective* discharges. The first is the ordinary example of excitement, diffusing or vibrating through good conductors; the second is the passage of electricity from good through bad or imperfect conductors, and comprehends all the varieties of luminous discharge; the third is that variety in which ponderable matter is set in motion under the influence. It has been shown by many experimentalists, that there is, in all cases of disruptive discharge, a transfer of material substances. If the ball of a prime conductor is gilded, and sparks are received from it on the back of a silver spoon for some time, traces of the gold will be evident on the silver. Many similar results are to be obtained with other bodies. The changes in the colour of the electric spark, when received from the surfaces of different bodies, appear also to show the transference of fine particles of solid matter. The electric light, in condensed air, is a very bright spark, and in an attenuated atmosphere it is faint and diffusive, like the light of the aurora borealis; in carbonic acid gas the light is white and intense; it is red and faint in hydrogen, yellow in steam, and green in ether or alcohol. The luminosity of electricity must not be regarded as evidence of light being a property of that principle; the luminous phenomena are due to the disturbance which excites that still more subtile agent—light,—so that it affects the organs of sight. Oranges, apples, and eggs may be rendered luminous by electricity, and even balls of wood: each of them presenting different colours.

It has already been stated that the heat evolved by an electric discharge is sufficient to produce the oxidation of metallic wire. Spirits of wine may be set on fire, and gunpowder exploded by the spark. In performing expeperiments of this kind, it is necessary, however, to diminish the disruptive force of the explosion. With gunpowder, unless some precaution is taken, the particles are thrown violently about; but if we interpose in the circuit a short tube of water, the resistance which this liquid offers, subdues this disruptive tendency, and the gunpowder placed between the wires of the universal discharger is instantly ignited.

The phosphorescent effects of electricity are not the least curious phenomena connected with this subtile agent. The researches of Father Beccaria and Mr. Pearsall have shown that a great variety of substances could be made to phosphoresce for some time, by transmitting an electric discharge along their surfaces. Calcined oyster-shells exhibit a very brilliant phosphorescence; selenite shines with a bright green light; calcareous spar and common chalk are also curiously affected. Borax and boracic acid, succinic acid and acetate of potash, carbonate and sulphate of barytes, and, according to Mr. Skrimshire, nearly every native mineral (not metallic ores or metals), become luminous in the dark after an electrical explosion. If the thumb is placed on the ends of the wires of the universal discharger, and the charge of a Leyden jar sent through it, it will be rendered very curiously transparent.

The rapidity of electric light is extreme: it has been experimentally shown by Wheatstone, that the duration of the light of a spark does not exceed the one-millionth part of a second. As the method by which this experiment was performed, when Wheatstone determined the velocity of electricity and the duration of its spark, is not generally understood, and being remarkable for its ingenuity, it is thought advisable to describe it.—Considerable lengths (about half a mile was employed by Wheatstone) of copper wire are so arranged, that there are three small breaks in its continuity,—one near the outer coating of the Leyden jar, one near the connection with the inner coating, and another exactly in the middle of the wire;—so that three sparks are seen at every discharge, one at the break near the source of excitation, another in the middle of its path, and the third close to the point of returning connection; these were, by bending the wire, brought close together. Exactly opposite to this was placed a metallic speculum, fixed on an axis, and made to revolve parallel to the line of the three sparks. When a spark of light is viewed in a rapidly-revolving mirror, a long line is seen instead of a point. It will be obvious that three lines of light will be seen in the revolving mirror every time a discharge takes place, and that if the first or the last differ in the smallest portion of time, these lines must begin at different points on the speculum.

When the mirror revolved slowly, the position of the lines was uniform, thus ; but when the velocity was increased, the lines of light appeared thus ; those produced by the sparks at either end of the wire being constantly coincident, but the spark evolved at the break in the middle being slightly behind the other two. From this, it appears that the disturbance commences simultaneously at either end of a circuit, and travels towards the middle. This has been adduced in proof of the two electricities. It is thus determined that electricity moves through the wire at a rate beyond 288,000 miles in a second. It will be evident to any one considering the subject, that the length of the line seen in the speculum, depends on the duration of the spark. When the mirror was made to revolve 800 times in a second, the image of the spark at ten feet distance, appeared, to the eye of the observer, to make an arc of about half a degree; from which its duration is calculated. To prove approximately the duration of the electric spark, a very pretty experiment has been devised, of the following kind.—A disc, painted in equal sections with the prismatic colours, is fixed on a centre, and, being connected with a multiplying wheel, it can be made to rotate with any known velocity. Such a rate is obtained that the colours are blended to produce a dull grey; the change of position being too rapid for either colour to leave its impression on the retina; the room is then darkened, and the light of a spark from a Leyden jar made to illuminate the rapidly-revolving coloured disc. It will now appear to the eye as if the colours were all at rest, every section of colour being distinctly visible; the interval of time occupied by the light of the spark being much less than that necessary for any one colour to move through a sensible space.

A resinous plate, such as that prepared for the electrophorus, affords us a very interesting method for exhibiting some of the attractive and repellent phenomena of electricity. If we take a charged Leyden jar, and draw any figures upon the resinous plate with the metal knob of the jar, and then dust over it a mixture of sulphur and red lead, we shall find, on throwing off the superfluous powder, that the sulphur will adhere along the lines traced by the positively charged knob. If we now draw other lines with the *outside coating* of the Leyden jar, and again dust the plate with the mixed powders, the minium, or red lead, will adhere to these lines, and the sulphur will be dispersed from them. This very interesting experiment of Leichtenberg's is merely a pleasing exemplification of the law of attraction and repulsion, already given. The resin is a bad conductor;—the metal knob has added electricity in one case,—the exterior metallic coating of the jar has taken electricity in the other; consequently, we have upon one surface the plus and minus conditions. The two bodies employed are also in different states, and they accumulate, according to their positive or negative conditions, upon these lines, which are in opposite states.

Atmospheric electricity has been the subject of investigation with many of our most eminent philosophers. The terrific grandeur of the thunder-storm has from the earliest periods of time attracted the attention of the great observers of nature; and we have some curious statements in the writings of Pliny and Herodotus, of the phenomena, which they invariably referred to supernatural agency.

Franklin was the first electrician who attempted to solve the problem of the identity of lightning and electricity, and his daring experiment marks a point in the progress of the science of the utmost importance. In 1749 Franklin proposed two methods, by which he imagined electricity could be drawn from the clouds; and in 1752, at his suggestion, Dalibard, residing near Paris, placed an insulated iron rod forty feet long above his house, and obtained sparks from it, accompanied by the usual snapping sound of electrical discharges. In the same year Franklin prepared a kite, with a pointed wire attached, the string, which terminated with a common key, being insulated by a silk cord at the lower end. This kite, in the month of June, was mounted, and after watching the passage of several clouds, Franklin perceived that the fibres of the hemp string were in a state of repulsion, and eventually, a shower of rain increasing the conducting power of the string, electric sparks were drawn from the extremity of the insulated key; thus confirming, by direct experiment, those speculations which had become to the American philosopher already positive truths. Romas, in France, repeated Franklin's experiment: he raised a kite 550 feet in the air during the prevalence of thunder-clouds; he obtained flashes of electric fire ten feet in length, and reports like the discharge of guns. Professor Richman, of St. Petersburg, erected an apparatus like that of Dalibard, and unfortunately, on one occasion, in August 1753, when experimenting, he was struck dead by an electric discharge, described as a large globe of blue fire, from the instrument of his own construction.

Saussure, Schubler, and others on the continent, Cavallo, Crosse, and many more in England, have investigated the peculiarities of the electricity of the atmosphere;

and the following are the more important results. Cavallo proved that the electricity of the air is usually positive; and this has been confirmed by other observers. With the sunrise the electricity increases; it diminishes towards noon, increases towards sunset, and decreases until midnight, when it again increases. It has lately been proved by Barlow and by Baumgartner, that electric currents are constantly traversing those electro-telegraphic wires which have any connection with the soil, and that the direction of these disturbances is determined by the sun's path; the main direction during the day being from the east towards the west, and the contrary during the night. Schubler, whose statements have been confirmed by Quetelet and Louyet, discovered that the atmospheric electricity increases from July to January, and then decreases, it being always more intense in the coldest weather. It is a remarkable fact, that the electrical intensity of the atmosphere during the prevalence of Asiatic cholera was much lower than had ever been before observed at the same season. Saussure found that electrical intensity was greatest in elevated situations,—that free electricity was nearly absent in narrow courts, alleys, and enclosed places, and that in crowded cities it was most intense in the squares and on the bridges.

When fogs, rain, hail, sleet, and snow prevail, a curious oscillation takes place in the atmospheric conditions. They generally come on with negative indications—the air is taking electricity from the earth; the atmosphere shortly becomes positive, and often every few minutes it changes from one to the other condition. Clouds produce similar disturbances, even though there is no deposit of moisture.

The origin of atmospheric electricity has been a subject of discussion; and it has been strenuously maintained, that it is due to the evaporation of the waters of the ocean. If we consider that every form of matter holds, condensed within and around it, a natural measure of electricity,—that every motion, every change of temperature, every influence of light, or of the chemical power of the solar rays, disturbs this,—it is clear that every change of atmospheric condition must involve a change of electrical equilibrium. Every manifestation we obtain appears to be good evidence in support of this view.

To ascertain the condition of the atmosphere in relation to electricity, various means have been adopted. If we fix a brass ball to the end of a fishing-rod, and pass it through the air, and then bring it in contact with a good electrometer, we can very readily measure off the electricity accumulated on the ball by the divergence of the index. Some experimenters attach arrows to an insulating string, and shoot from a bow. In all observatories, pointed and insulated rods are raised to some considerable height. Mr. Crosse, of Bromfield, has more than a mile of insulated wire extended between pointed conductors, raised a hundred feet high; and Mr. Weeks, of Sandwich, had a similar arrangement for his electrical gatherers.

It will now be understood that a thunder-storm is only an effort of nature to effect a restoration of equilibrium. Clouds have become charged in excess: they are positive to the earth, in precisely the same manner as one side of a coated pane of glass is to the other; the air being the interposed medium. Lightning is nothing more than the disruptive discharge of many miles, perhaps, of electrified cloud. It may be that the discharge is from one cloud to another, or from a cloud to the earth. That this is but an effort to restore an equilibrium, is often shown by the phenomenon called the *return flash*. It not unfrequently happens, when we view a thunder-storm under favourable conditions for observation, that as the discharge is made at one end of an accumulation of clouds, a flash is seen to pass from the earth to the cloud at the other extremity: this phenomenon is illustrated in the vignette to the present chapter. To this cause is to be attributed the fact that men and animals are sometimes killed at a distance from that spot over which the storm appears to pour its fury; the restoration of equilibrium being effected through their bodies.

Sometimes the lightning is *zigzag*, or "forked:" this is due to the resistance of the air. At other times it appears to run along a line in waves, called *chain lightning*: this is due to a line of moist air which affords an easier path for the discharge. *Sheet lightning* is a discharge behind the dense cloud, so that its path is hidden from the eye; the lambent lightning which does not amount to explosions, seen of a summer's evening, is also termed sheet lighting. *Globular lightning*, which is not very common, is of the character of glow-discharge, and it may be regarded as similar to the process of emptying a Leyden jar of its charge by a pointed rod. These globes of electricity are, however, in nature, generally followed by a burst of thunder and lightning.

The noise of thunder arises from the expansion and subsequent collapse of immense masses of air, the noise being continued by reverberation among the masses of dense cloud which usually occupy the atmosphere at such times.

The *Fires of St. Elmo*,—the phenomena called Castor and Pollux by the ancients,—the *feu de St. Elme* of the French,—the *Elmsfeuer* of the Germans,—known also by the name of *Helen's light*, *Corpo Santo*, and *Comazants*,—have the appearance of brushes or balls of fire on the masts of ships, and are of the character of discharge by pointed bodies: many meteoric effects are of this kind.

It is commonly remarked, that after a severe thunderstorm the atmosphere has a peculiar smell, and when a building has been struck by lightning it is often described as giving an odour resembling that of sulphur or phosphorus. The same smell may be detected when an electrifying machine has been for some time excited in an apartment. This appears to arise from the formation, by some peculiar process, with which we are unacquainted, of a new combination of oxygen with the water of the atmosphere, or, more strictly speaking, the formation of a peroxide of hydrogen. This compound, which has for many years interested Professor Schönbein, and has been termed by him Ozone, from its smell, possesses many peculiar properties. It appears to attack most energetically all metallic bodies, even those stated to be the least oxidizable, and to change the character almost immediately of all organic compounds. It is found to exist in the atmosphere at all times, but the proportion in which it is detected varies with every alteration in the electrical character of air, it being in excess when the electrical intensity is greatest, and falling to a minimum when this reaches its lowest point. The presence of ozone may be detected in the following manner:—Mix a little iodide of potassium with a solution of white starch; smear some slips of writing-paper with this, and place them in a current of air,—as in an open window. In a short time, if ozone is present, the paper will become coloured, this coloration arising from the decomposition of the iodide of starch, which is of a purple hue.

When an electric discharge from a thunder-cloud has passed through a house, it has not unfrequently been observed that knives and other steel utensils have become magnetic. We may prove, by very easy experiments, the power of machine electricity to induce magnetism. If we place a sewing-needle upon a piece of copper plate on the table of the universal discharger, and then send the charge from a Leyden jar across it, it will become strongly magnetic.

The physiological effects of machine electricity are well known. The shock arises from the disturbance of the statical electricity of our bodies. The discharge from a battery of Leyden jars is sufficient to kill large animals, particularly if sent through the skull.

Faraday has shown that chemical changes can be effected by a succession of discharges from an electric jar. Sulphate of copper, sulphate of indigo, and iodide of potassium, among other salts, have been decomposed by the continued passage of charges through their solutions. Water has been decomposed in small quantities by the spark; and it is well known that nitric acid is formed when atmospheric air is enclosed in any vessel through which sparks from a machine can be readily passed.

The examination of phenomena which connect themselves with animal electricity, is referred to the next section, which will embrace the laws and operations of chemical electricity, to which the electricity of vital action appears peculiarly to belong.

A knowledge of the laws which electricity obeys, has enabled man to protect himself from its destructive influences. Lightning conductors have arisen from the fine experiment of Franklin, who first showed that an electric cloud could be discharged by means of pointed rods, and its contents conveyed harmlessly into the earth. A prejudice prevailed for a long period against the use of the lightning conductors,—the *paratonnerres* of the French,—it being supposed that they *attracted* the lightning. This idea still prevails in many minds, and they see reason for it in the fact that the highest bodies, as trees, church steeples, and tall chimneys, are usually the objects of destruction, —their inference being that they have attracted the lightning. The truth is, a cloud charged to saturation with the electric fluid, floats over the earth, until it eventually comes within discharging distance, and it matters not what the object is that presents itself, it forms the channel through which the discharge is made. If it is a bad conductor, as a tree, the mast of a ship, or a piece of masonry, the whole is rent or shaken, in the struggle between the exciting fluid and the resisting medium; if, on the contrary, a good conductor is presented to it, the current flows down it as tranquilly and harmlessly as water through a pipe. There is no attraction, but the lightning takes the road of least resistance.

Sir William Snow Harris, who has devoted much attention to this subject, gives the following directions for the construction and adaptation of lightning conductors.—One of the best conducting metals must be selected, copper having many advantages over other metals. Ohm gives the following table of their conducting powers:—

Copper	100
Gold	57·4
Silver	35·6
Zinc	33
Iron	17·4
Tin	16·8
Lead	9·7

The capacity of the metal used should be such as to carry off any amount of the electric fluid which it is at all probable may be passed through it. It has been found that a copper rod three-quarters of an inch in diameter is capable of resisting the heating effect of any discharge of lightning which has been recorded. The conductor should consist of several branches, with pointed rods projecting freely into the air, from distant summits of the building, and connected with the main rod; it should penetrate the soil to some depth, and, where practicable, be connected with running water, a drain, or some good conducting channel. In ships, it is now usual to fix the conductors to every mast, and connect them with bands of copper passing through the sides of the ship under the beams, and with the large bolts leading through the keel. By such an arrangement, well carried out, every building or ship may be most effectually protected from the possibility of danger. By similar arrangements, studded among the vineyards of the south of France, known as *paragrêles*, the electrical hailstorms, which frequently destroyed the crops, are said to have been materially checked. Thus, by availing himself of that knowledge which can be obtained by inductive science, man is enabled to protect himself against many of the great disturbances of nature.

GALVANISM, or VOLTAIC ELECTRICITY, as it has been called,—from Galvani and Volta, who were the means of placing a new form of electrical force in the hands of the philosopher,—is the production of electrical disturbance by chemical action. The story of Galvani is variously told; but, whether we receive the narration which makes him hang frogs by iron hooks to bronze railings, or the one which tells us that the chain from the prime conductor of his electrical machine was left by accident in contact with a silver dish, upon which were some frogs prepared for cooking, certain it is, that Galvani was the first to investigate the phenomenon of muscular disturbance under electrical excitation. The facts were known long before, but Galvani, examining all the circumstances, was led to the discovery that this peculiar electrical excitement took place when a circuit was formed of three parts, a muscle, a nerve, and a metallic conductor, each placed in contact with the other two. Galvani gave the name of animal electricity to the phenomenon, and thus restricted inquiry within certain physiological limits.

Volta took up the investigation: he showed that the physiological considerations were quite foreign to the subject, and regarded the contractions of the muscles of the frog as merely a delicate means of detecting electrical currents. The pile of Volta consists of a series of metal plates, arranged in pairs, one of each pair being a more oxidizable metal than the other. The action of contact has been already noticed; and by pressing together a zinc and a copper plate, several times, in contact with the condensing plate of the electrometer, Fig. 139, a divergence of the gold-leaves is effected. This was at one period referred to a tendency of bodies in contact to assume opposite electrical states; but it is now clearly established as the result of weak chemical action, this being greatly quickened by the contact of dissimilar metals;—zinc, for example, oxidizing more rapidly in contact with copper than when alone. The researches of Faraday and Becquerel have determined that *no chemical action takes place without a development of free electricity*, and the manifestation of electrical phenomena is, in nearly all cases, known to be accompanied by chemical action.

The simplest mode of examining this point, presents itself in the construction of the dry piles of De Luc and Zamboni already described. A pile of this kind, carefully arranged, and well secured in glass tubes with brass caps, will keep in action for many years. The amount of chemical action is exceedingly small, but small as it is, it developes a certain quantity of electricity, which is communicated to the brass caps. If two such piles are arranged near each other, one having the silver at the top, and the other the zinc, and a light body is suspended between them, it is continually attracted and repelled, thus producing a sort of electrical perpetual motion. The influence thus excited was termed by Volta, the *electromotive force*; and those bodies which will by contact give rise to it, are called *electromotors.*

Such bodies, possessing these powers in different degrees, admit of arrangement in definite order; those which stand at the head of the scale being more *excitable* than e which stand below it. The following is given from results obtained by several of the most successful culti- rs of this branch of science :—

+
Zinc.
Lead.
Cadmium.
Tin.
Antimony.
Bismuth.
Iron.
—

+
Brass.
Copper.
Silver.
Gold.
Platinum.
Graphite.
Charcoal.
—

two of these metals brought together will give rise to the tromotive force; but, the more remote they stand from other in the scale, the more decidedly will the chemical tricity be developed. Zinc and lead will produce a aic pile, but it will be much less active than zinc and , or the same metal and copper, and still less than the bination of zinc and platinum or charcoal.

n all voltaic arrangements, chemical action is set up n the positive metal, and the negative metal performs part of a condenser, upon which the electricity appears ccumulate. But we must now examine the construc- of the voltaic pile and battery.

f a piece of clean zinc is placed upon the tongue, and a er coin below that organ, no perceptible effect is pro- ed; but upon bringing their outer edges to touch, a inct thrill will pass through the tongue, a metallic taste will diffuse itself, and, if the eyes are closed, a sensation of light will be evident at the same moment.

If a dead frog, or a small flat fish, the flounder, is placed upon a copper or silver dish, and a plate of zinc is laid upon its back, no action will be observed; but if a copper wire is pressed into close contact with the zinc at one end, and if the other end is made to touch the dish, a convulsive movement will instantly take place, which will be renewed every time contact is made or broken. These very simple forms of experiment lead us directly to the construction of the voltaic or galvanic battery.

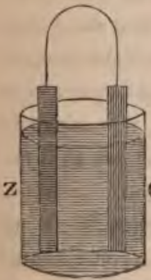


Fig. 152.

The annexed figure is introduced for the purpose of illustrating all the elementary phenomena of the hydro-electric arrangements. Here we have a zinc and a copper plate, z, c (Fig. 152), connected by a copper wire, placed in a glass jar containing a fluid,—let us suppose it to be water of the ordinary character. The visible result will be the oxidation of the zinc plate, the want of any chemical action on the copper. If they were, both being equally bright and disconnected, plunged into a similar fluid, they would be dimmed by oxidation in nearly an equal degree in equal times; chemical action taking place upon each of them.

We must remember the law, confirmed by a most extensive series of experiments, that *every chemical change* *gives rise to electrical disturbance.* Now, placing the zinc and the copper plates, without the connecting wire, in water, rendered slightly acid to increase the chemical action, we shall find, the moment they are introduced, that the zinc plate will become covered with bubbles, which, gradually enlarging, will quit the metal, and escape through the fluid:—these bubbles are hydrogen; and for every equivalent thus liberated, a corresponding equivalent of oxygen has combined with the zinc to form oxide of zinc.

It has already been stated that the quantity of electricity which holds a particle of water together, is exactly equal to that required to decompose it. In the chemical decomposition of the water, and the chemical composition of the oxygen and zinc, we have a disturbance of this combining force, and this circulates ordinarily between the water and the zinc; but, if the copper is brought in contact with the zinc by means of the copper wire, the electricity liberated is at once accumulated on the copper plate. This condensed electricity protects that metal from chemical action; but a circulation is established from the zinc to the copper, through the water, and from the copper through the wire back to the zinc.

Metallic contact is not necessary to the production of voltaic phenomena. The following experiment of Faraday is very instructive. Prepare a plate of zinc, ten or twelve inches long and two inches wide, and clean it thoroughly; provide also two discs of clean platinum, about one inch and a half in diameter; dip three or four folds of bibulous paper into a strong solution of iodide of potassium; place them on the clean zinc at one end of the plate, and put on them one of the discs of platinum; finally, dip similar folds of paper, or a piece of linen cloth, into a mixture of equal parts nitric acid and water, and place it at the other end of the zinc plate, with the second platinum disc upon it. In this state of things no change of the solution of the iodide will be perceptible; but if the discs be connected by a platinum wire for a second or two, and then that over the iodide be raised, it will be found that the *whole* of the surface beneath is deeply stained with *evolved iodine*.

From these experiments, the construction of the voltaic pile will be better understood. Fig. 153 represents the mode of arrangement: discs of zinc and copper are placed in pairs, and often these are soldered together, but this is not necessary; between each pair a piece of cloth, or pasteboard, wetted with weak acid, or with a solution of salt, is laid. A hundred pairs of plates thus arranged will produce very powerful effects. This, and another form of battery, was devised by Volta; from the second variety, the *couronne de tasses*, nearly all the modern forms of battery appear to be derived. Take six or twelve wine-glasses, and nearly fill them with acidulated water; solder to the opposite ends of short pieces of copper wire, a small plate of copper, and another similar one of zinc; place these in the glasses so that the plates of each pair are in different ones,—

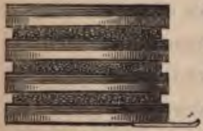


Fig. 153.

copper, for example, in the first glass, and its connected zinc plate in the second, the copper of the second pair in the second glass, the zinc in the third, and so on, to the end; a copper plate being at one end of the series, and a zinc plate at the other.

Voltaic batteries may be divided into three varieties:—1st, those composed of two different electromotors and one fluid; 2nd, those formed with two dissimilar metals and two fluids of different chemical characters; 3rd, batteries with one metal and two dissimilar fluids.

Among single-fluid batteries we have the old battery of *Cruickshank*, which is merely the pile already described fixed in a box, so that, for the cloth, an acid or saline fluid is substituted; *Wollaston's* battery, in which every plate of zinc is placed between two plates of copper; *Œrsted's* trough, which consists of troughs of copper in which the zinc is placed without touching the other metal at any part, and which also serves to hold the fluid; *Hare's spiral* or *calorimotor*, which is formed by rolling zinc and copper sheets into a spiral, so that the two metals are in every part half an inch asunder;—this arrangement is placed in a vessel containing the diluted acid solution. The enormous battery constructed by *Mr. Children* was of this class, being plates six feet long, and two feet eight inches broad. Among modern batteries, *Smee's* is the best form of those in which a single fluid is employed: it is of the following description.

Two plates of amalgamated zinc, z, z, are clamped to a piece of wood *w*, by means of a bent piece of brass *b* (Fig. 154), which is furnished with a binding screw. Between these two is fixed a plate of platinized silver S, which is prepared by immersing it for a short period in a solution of chloride of platinum whilst connected with the negative end of a voltaic battery, by which process the platinum is deposited on the silver in very fine powder, forming an infinite number of points, from which the hydrogen is freely evolved by the action of the dilute sulphuric acid A.

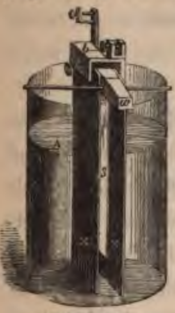


Fig. 154.

The second order, or those having two dissimilar fluids and metals, comprehends the batteries of *Daniell*, *Grove*, *Sturgeon*, and *Bunsen*.

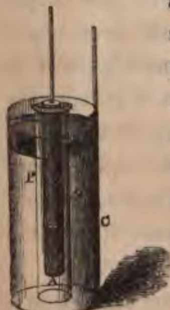


Fig. 155.

Daniell's battery (Fig. 155) consists of a copper vessel C, which holds the liquid—solution of sulphate of copper—and serves as the negative plate at the same time. In this is placed a cell, P, of porous earthenware, in which is put a solution of sulphuric acid, and the zinc cylinder A. At the top of the copper trough is a small perforated shelf, upon which are placed crystals of sulphate of copper, the object of these being to maintain the solution at a point of saturation; for, as the zinc oxidizes in the inner cell, the sulphate of copper is decomposed in the outer one. To charge this battery of Daniell, one part of sulphuric acid to fifty of water is placed in the porous cell, and a saturated solution of sulphate of copper in the outer trough. This battery is remarkable for its permanency of action; and if means are adopted for supplying fresh acid in the zinc cell, it may be maintained in energy for a considerable period.

Grove's battery (Fig. 156) consists of a cylinder or U-shaped plate of zinc Z, which is placed in diluted sulphuric acid A, in the outer glass or glazed cell; an unglazed, and consequently porous, earthenware cell, N, is placed within the zinc; this is filled with strong nitric acid, in which is immersed a plate of leaf platinum P. The intense action of this battery renders it very valuable as an agent in electro-chemical researches.

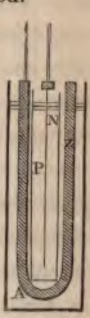


Fig. 156.

Bunsen's battery (Fig. 157) is but a modified form of Grove's: in both, nitric acid and dilute sulphuric acid are employed; but in Bunsen's a cylinder of coke is substituted for the platinum. These cylinders are made by well mixing together coal and coke, pressing them in moulds, and subjecting them to repeated firing, by which they

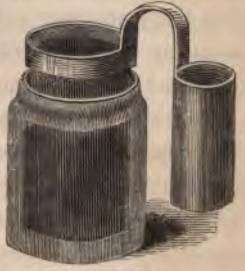


Fig. 157.

are rendered very coherent. The mode of connecting the zinc cylinder of one pair with the coke cylinder of another is shown in the preceding figure. In Grove's and in Bunsen's battery the nitric acid is decomposed, and the fumes of nitrous acid are unpleasant and injurious; these batteries should, therefore, always be placed outside a window, the wires from them being brought into the apartment. It has been calculated by Jacobi and others that it requires about sixteen times the surface of copper to produce the effect of any surface of platinum, but that in electrical effect carbon and platinum are very nearly equal. The carbon battery of Bunsen has not been much used in this country, and there are many practical inconveniences connected with it. It not unfrequently happens that the nitrous acid attacks the zinc collar very energetically, and erodes it so rapidly as to destroy the metallic connection; and this, in an extensive series, and in the middle of a tedious experiment, is exceedingly annoying. The platinum in Grove's battery is usually connected with the zinc plates by clamps of wood, and the battery may be relied on for many hours.

The third form of battery, or that in which two dissimilar fluids are used and but one metal, or its equivalent, comprehends the batteries of Becquerel, Wöhler, and Reinsch, and the curious gas battery of Grove. ·If into one arm of a U-shaped tube,—a little lump of clay, or other porous material, being placed at the bottom in the middle of the tube,—we pour a solution of caustic potash, and of sulphuric or any acid into the other arm, these two combine, slowly, to form a salt. If two pieces of platinum wire are placed in the open ends of the arms, a current of electricity will be found to circulate. A very simple method of constructing a battery on Becquerel's principle is the following:—Take two watch-glasses, and having placed in one of them a solution of common salt, and in the other a solution of nitrate of silver, connect them by a little bundle of cotton threads. The two fluids, ascending along the capillary fibres of the threads, combine in the middle, and form chloride of silver. If a small piece of platinum wire is placed with either end in a glass, it will be found, after a few hours, that crystals of metallic silver will be formed around the wire in the solution of the silver salt, this crystallization being due to the electrical excitation conveyed along the wire from one solution to the other.

Grove's gas battery deserves particular description. In a series of jars are placed plates of platinum, two in each,—one a narrow slip, the other a square plate, united together near the top; a set of tubes are connected with a main tube, which terminates at one end in a large bell-shaped opening, and at the other end a glass stopper is adjusted. The jars are nearly filled with acidulated water, and an additional larger jar, in which is fixed a cube of zinc, is filled with diluted sulphuric acid. The connected tubes, the stopper being removed, are then placed in the jars, so that they cover the platinum;

the bell-jar being over the zinc; they are, of course, filled with fluid to the level of that in the jars, and then the stopper is firmly adjusted; the hydrogen forming by the action of the zinc rises at the bell-shaped end of the tube, and gradually fills the others, depressing the fluid, until the platinum strips are left nearly dry, and the acid falls below the zinc, when chemical action ceases. The strips of platinum are now exposed to the action of hydrogen, and the square plates to the oxygen of the atmosphere. A current of electricity will now be generated, and circulate along the connecting wires. A series of ten cells are sufficiently powerful to effect the decomposition of water, and give minute sparks.

The charcoal battery of Reinsch consists of a glass jar and a porous cell within it. Both between the jar and the cell, and in the cell itself, is placed coarsely-powdered charcoal: in one compartment the charcoal is saturated with nitric acid, and in the other with sulphuric acid. A rod of coke or charcoal is placed in each, and a wire being fastened to the exposed end, upon closing or opening the circuit electricity will be manifest.

In all the useful batteries zinc is the most important element, and the process of amalgamating it, or coating its surface with mercury, which was introduced by Mr. Sturgeon, by arresting the merely local chemical effect which is found to act in certain defined circles, materially improves the condition of the battery. Even impure zinc, amalgamated, does not decompose the water of dilute sulphuric acid, but still has such an affinity for oxygen, that the moment it is touched by copper, a powerful electric excitement is produced. Such are the sources from which, ordinarily, we obtain voltaic electricity; the action of different bodies in relation to that force must now be noticed. A given amount of electromotive power is generated by the chemical action in the battery, and this can be communicated to almost any distance by *conductors*, the only limit to this being the *resistance to conduction* offered by the *conducting body*.

The conducting power of a body varies with its physical structure; the following table, by Becquerel, shows the degree of this in a few of the metals. The numbers represent the relative lengths of wires of equal diameters which conduct the same quantities of electricity:—

Copper	100	Iron	15
Gold	93	Lead	8
Silver	73	Mercury	3
Zinc	28	Potassium	1
Platinum	16		

All bodies vary in this power of conducting *current* or *progressing* electricity. The metalliferous ores are mostly good conductors; the rocks as commonly are insulators, the amount of resistance they offer preventing the progress of the electrical excitation. Faraday has shown that the law of *the assumption of conducting power during liquefaction, and the loss of it during congelation*, is very general.

Water is not a bad conductor, but ice will not conduct through the thinnest film.

In the battery itself, a large amount of resistance has to be overcome by the electromotive force:—1st, the resistance offered by the length of every plate in the series, and, 2nd, that which the electricity has to overcome in passing from a solid to a liquid, or the contrary. The greater the intensity of the battery, the less, relatively, is the resistance: it would appear that the impulsive force of an intense action broke through resisting powers, which a feeble action could not overcome.

The law of Ohm, which is applicable under all circumstances, fully expresses the great fact:—*the intensity of an electric current, when a battery is in action, is directly as the whole electromotive force in operation, and inversely as the sum of all the impediments to conduction.*

It must be ever borne in mind that the excitation of electricity is directly as is the amount of chemical action, and as this increases with the amount of surface exposed, we have the means of greatly increasing the power. The impediments to conduction are of two kinds, one in the battery, and the other in the conducting wires; therefore the increase in the number of plates in a battery, at the same time as they expose a much larger extent of surface to chemical action, offer a constantly increasing amount of resistance to the passage of the current. Thus, the *quantity of electricity* cannot be increased with the increase of metal plates. A single pair of zinc and platinum plates throws as much electricity into the form of a current by the oxidation of an equivalent of zinc, as would be circulated by the same alteration of a thousand times that quantity, which would be nearly five pounds of metal oxidized at the surface of the zinc plates of a thousand pairs placed in regular battery order. For it is evident, that the electricity which passes across the acid, from the zinc to the platinum in the first cell, and which has been associated with, or even evolved by, the decomposition of a definite portion of water in that cell, cannot pass from the zinc to the platinum, across the acid in the second cell, without the decomposition of the same quantity of water there, and the oxidation by it of a like equivalent of zinc. The same result occurs in every other cell: the electro-chemical equivalent of water must be decomposed in each, before the current can pass through it; for the quantity of electricity passed, and the quantity of the electrolyte decomposed, must be the equivalents of each other. The action in each cell, therefore, is not to increase the amount set in motion in any one cell, but to aid in urging forward that quantity, the passing of which is consistent with the oxidation of its own zinc; and in this way it exalts that peculiar property of the current which we endeavour to express by the term *intensity*, without increasing the *quantity* beyond that which is proportionate to the quantity of zinc oxidized in any single cell of the series. (Faraday.)

Formerly, the direction of improvement in the voltaic battery was towards gaining power by the increase of the number or size of the plates. Sir Humphry Davy employed a battery of 2,000 pairs of plates, each plate having a surface of thirty-two square inches; and Mr. Pepys made a battery for the London Institution, consisting of a zinc and copper plate, each fifty feet long and two wide, rolled into a coil, with horse-hair ropes between them to prevent their touching. Now, however, with ten or twenty pairs of plates, we can produce effects in every respect superior to those which resulted from the use of such cumbrous, troublesome, and costly arrangements, whether we regard the calorific, chemical, or magnetic power of the electro-chemical current.

Calorific phenomena.—Heat is evolved whenever a voltaic excitation is sent along a conducting body, the intensity of the heat being greatest when the plates are large; and it may therefore be referred rather to *quantity* than intensity. The heat is also regulated by the conducting power of the body through which the current passes; bad conductors of equal length and thickness becoming much hotter than good ones in the same time; indeed, the experiments of Riess, Faraday, and Becquerel prove that the relative power of metals for acquiring heat, by electric excitation, is directly as their retarding powers, or their resistance:—thus, if we link together pieces of copper, iron, silver, and platinum, and pass the voltaic current along them, they will be found to be unequally heated, the platinum being the most, the copper the least so.

The easiest mode of showing by experiment the heating power, is to connect the poles of a battery by means of a fine platinum wire of a certain length—it may become hot, but if sufficiently long it will not become red; shorten the wire, and it becomes immediately incandescent; shorten the wire still more, and it will become white hot and melt. If such a wire is carried through saline water in a watch-glass, the liquid will presently boil, and if through alcohol or ether, or if we place over the wire phosphorus or gunpowder, they will be inflamed. This power has been applied to the purpose of firing mines of gunpowder, and for producing explosions of the same substance under water. The blasting of our chalk cliffs has been effected on a very large scale by this means. The process is as follows:—The wires from a sufficiently powerful battery are connected by a piece of platinum, which is placed in the midst of a mass of gunpowder, or, if many holes have been bored, several portions of wire are thus connected by platinum, which is, by bending the wire on itself, arranged so that the platinum can be placed at the bottom of the hole, and the powder poured in upon it. When all is properly adjusted, connection is made with the battery, and immediately all the pieces of platinum become sufficiently hot to explode, at the same moment, the gunpowder in a great number of holes.

The most refractory substances may be most readily fused by the heat of the voltaic battery. The metals readily yield to its influence. Gold burns with a bluish light, silver with a beautiful green colour, and the combustion of the other metals is always accompanied by very striking results; while platinum and palladium may be fused in very large quantities. The earthy minerals may be fused in the arc between the poles of a battery. Sapphire, quartz, slate, and lime are readily liquefied, and the earths reduced to their metallic conditions. The diamond, if placed *in* a piece of graphite at one of the poles, and the other pole is brought over it, so as to spread the luminous arc over the gem, is at first fused, it presently boils up, and, spreading open, is converted into coke,—a most striking proof of the fact that charcoal and the diamond are but different physical states of the same body, *carbon*.

Becquerel suggests that the heat thus obtained may be applied to many useful purposes, particularly for smelting gold and silver ores in those mining districts where fuel is not easily obtainable.

The *luminous* effects of the battery connect themselves directly with its calorific excitation, and, as Draper has shown, all bodies become luminous when the temperature produced by the current reaches 1000° Fahrenheit.

A very small voltaic arrangement is sufficient to produce a spark of light every time the circuit is closed or opened. If the two ends of wires proceeding from the opposite poles of a battery are brought nearly together, a bright spark will pass from one to the other, and this takes place even under water, or in a vacuum.

The most brilliant luminous effects are, however, produced between charcoal points connected with the terminal poles of batteries of high intensity. *The electric light* is produced by such an arrangement. The poles, being armed with hard box-wood charcoal or compressed carbon, are brought within a certain distance, which varies with the power of the battery employed, and a beautiful arc of pure white light circulates between these points. When a large and powerful arrangement is employed, the intensity of the light is extreme, and by means of reflectors its illuminating powers can be extended for many miles. Public hope has been from time to time excited by displays of this phenomenon of electric power, but it is in many respects impracticable as an illuminating agent. The expense, in addition to other objections, is a great obstacle to its introduction. In examining any of those physical phenomena, artificially produced, we must not forget that in every case, whether heat, light, or electricity is obtained, there is for any given effect *a consumption, a change of state, of a definite proportion of some material element.* Coal is burnt in our furnaces, to give us heat; oil in our lamps, to furnish us with light; and zinc and acid in the battery, to produce any of the phenomena consequent upon voltaic action.

The physiological effects of the battery are of the same character as those produced by frictional electricity; but as the former are continuous, and the latter transitory, some of the sensations are different. Upon grasping the two ends of the connecting wires of an intense battery with wet hands, a convulsive tremor passes through the muscles. Galvani's experiment must be regarded as the fundamental one of this very peculiar class. The legs of a frog are prepared by being denuded of their skin, still allowing them to be attached to a portion of the spine;—place the spinal end on a plate of zinc, and the feet on a plate of copper; pass a wire from one piece of metal to the other, and the moment the circuit is completed and electrical progression takes place, that instant the frog's legs will move as if with life. Aldini's experiments went strongly to support the views of his uncle Galvani, who believed in the existence of a peculiar form of electrical excitement which existed in all animals, which was called by him *animal electricity,* and which was rendered sensible by the metals, but not produced by them. Modern researches appear to show, that in every instance in which electricity is manifested, it is connected with chemical action. It is inferred, therefore, that electricity is not a function of vitality, but the result of those chemical changes which are constantly going on in all living organic bodies. In the animal economy we have carbon combining with oxygen in the process of respiration, and in all the processes of assimilation we have chemical changes constanty occurring. In the operation of the laws of diffusion, and by the influence of endosmose action, acid and alkaline matters are separated from each other. It has been shown by Donné and by Bird, that an arrangement of a solution of common salt and of muriatic acid divided from each other in a cell, by a piece of animal membrane, through which, by endosmose, they slowly combine, is quite sufficient to produce electrical excitement.

A very numerous class of experiments have been published, which would appear to afford some evidence of vital electricity. An experiment by Matteucci will well illustrate the general conditions. This electrician introduced a plate of platinum into the stomach of a living rabbit, placed another on the liver, and connected both with a galvanometer, the needle of which was instantly deflected 20°, this deflection being observed to be constant; the nerves and vessels passing into the abdomen were divided above the diaphragm, and immediately the needle fell back to 3°, and on cutting off the head of the rabbit by a sudden blow, this slight indication of a current immediately ceased.

M. du Bois Raymond has recently brought forward some experiments which appear to show that every muscular movement gives rise to electricity. At the end of two wires, which are securely fastened by the other ends to a galvanometer, are attached two plates of platinum, which are placed in separate glasses of water. The index finger of the left hand being dipped into the water of one glass, the right arm is contracted very powerfully and again extended; the finger being then plunged into the water in the other glass, by which the galvanometer is deflected, indicating the existence of a current produced by the muscular force exerted.

The phenomena of animal electricity are still involved in much difficulty, but there are a sufficient number of facts collected to warrant the adoption of the following views. An electric circulation passes from the stomach to the liver, which ceases with life, or on the division of the nerves connected with these organs; in muscular movement a disturbance of electrical equilibrium is produced, which, when the nervous system is severed, entirely ceases.

Herschel has a very beautiful speculation upon this subject; he says, "If the brain be an electric pile constantly in action, it may be conceived to discharge itself at regular intervals, when the tension of the electricity reaches a certain point, along the nerves which communicate with the heart, and thus to excite the pulsation of that organ." Dr. Arnott appears also disposed to look to the same source for the active agent which keeps up the regular pulsations of the heart.

This idea has been carried much further by some, and loosely-contrived experiments have been brought forward in support of the view that all vital phenomena are due to electricity; indeed, certain resemblances have been thought to be traceable between the phenomena of a voltaic battery and the organs of sense. Galvanic noses and electrical ears have been made, and, by a series of poor analogies, very unphilosophical deductions have been supported, to prove that the human senses are but galvanic phenomena. We may rest assured that life is infinitely superior to the most exalted form of physical force; that sensation is dependent upon a still more refined power, which must be regarded as spiritual; and that, although we may detect electrical phenomena in the processes of vitality, they are the effect, and not the cause. Man, with all the appliances of his ingenuity, by all the aids of the most refined system of science, must ever stop at the threshold of life. Physical science will never enable him to construct a voltaic nose which can smell, to form a galvanic ear which shall be sensible of sound, or to adjust an electrical eye in which the solar rays can awaken the sense of seeing.

We have a few remarkable instances of animals which possess a power of generating electricity, and evolving it by an effort of their will. This remarkable effect is most striking in the two fishes, the *torpedo* and the *gymnotus*; but it is also detected in the *tetraodon*, *silurus*, *rhinotatus*, and *trichiurus*.

The *Torpedo* (Fig. 158) is a genus of fishes belonging to the family of the rays. The electrical apparatus consists of small membranous tubes, disposed like the cells of the honeycomb, and which are filled with a mucous substance. This singular arrangement, which is shown in the annexed woodcut, is disposed between the head-gills and the pectoral fins, and it is abundantly supplied with

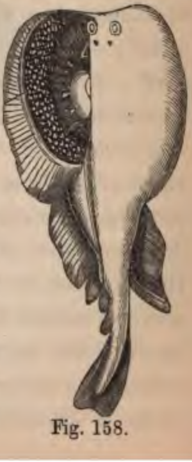


Fig. 158.

nerves radiating from the eighth pair, or pneumo-gastric nerves. These creatures have the power of striking or benumbing their prey, and thus rendering them easy captives.

Dr. Davy succeeded in decomposing acidulated water by the electricity of the torpedo, and producing the evolution of iodine from the iodide of potassium. He has heated platinum wire, and rendered iron magnetic, from the same source. The power of communicating an electric shock depends entirely on the nervous system, for the heart may be taken out, and the fish flayed, without its losing the power; but if the nerves are divided, no further electricity can be evolved.

The *Gymnotus* (Fig. 159), or electrical eel, is an inhabitant of many fresh-water rivers in South America. The following description of them is derived from Humboldt.—"The marshy waters of Bera and Rastro are filled with numberless electrical eels, which can at pleasure send a powerful discharge from any part of their slimy, yellow-spotted bodies. These gymnoti are from five to six feet in length, and are powerful enough to kill the largest animals when they discharge their nervous organs at once in a favourable direction. The capture of the gymnoti affords a picturesque spectacle. Mules and horses are driven into a marsh,

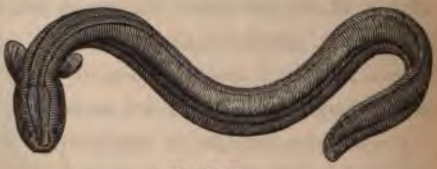


Fig. 159.

which is closely surrounded by Indians, until the unwonted noise and disturbance induce the pugnacious fish to begin an attack. One sees them swimming about like serpents, and trying, cunningly, to glide under the bellies of the horses. Many of these are stunned by the force of the invisible blows; others, with manes standing on end, foaming and wild, with terror sparkling in their eyes, try to fly from the raging tempest. But the Indians, armed with long poles of bamboo, drive them back into the middle of the pool. Gradually the fury of the unequal strife begins to slacken. Like clouds which have discharged their electricity, the wearied fish begin to disperse; long repose and abundant food are required to replace the galvanic force which they have expended. Their shocks become gradually weaker. Terrified by the noise of trampling horses, they timidly approach the bank, where they are wounded by harpoons, and cautiously drawn on shore by non-conducting pieces of dry wood."

A gymnotus brought to this country by Mr. Porter, and purchased by the proprietors of the Adelaide Gallery, afforded Dr. Faraday the means of examining the phenomena it exhibited, and of proving the identity of its electricity with the more common forms of that force. Shocks were given and received, the galvanometer was deflected, magnets were made, chemical decomposition was effected, heat appeared to be produced, and light was several times evident in the production of the spark.

Professor Matteucci has had abundant opportunities of experiment with, and examining of, the torpedo, and gives the following as his views.—The electric organ the torpedo, and of all the electric fishes, is composed o great number of elementary organs, and the element organ is nothing else but a nervous fibril in contact w a small cell filled with albumen.

The *Silurus*, or cat-fish, is found in some of the Afri rivers, but it is little known; and with the other fishes nam our acquaintance is still less. It is stated that a Chil spider has the power of benumbing the hand by whic is touched, and some other creatures have been said possess this power, but it is doubtful.

The chemical effects of the voltaic battery were first served by Carlisle and Nicholson; the enormous power the current rendered by Davy available in decomposing alkalies and earths, and Becquerel, Crosse, and others have shown that many of the phenomena of nature can be imitated by its influence. In the annexed plate (Fig. 160) is given a very simple arrangement by which the decomposition of water is readily effected. The two little cups shown on the base have wires of platinum connected with them, which are carried into the vessel in which the water is placed, and these cups are filled with mercury to ensure

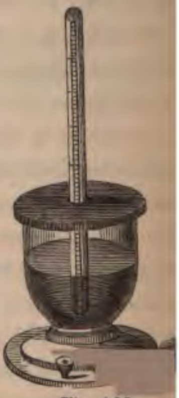


Fig. 160.

metallic contact when required. A graduated tube, filled with water, is placed over the wires in the glass, and the wires from either end of the battery being placed in the mercury, gas is immediately evolved from both the wires and collected in the tube. This gas is a mixture of hydrogen and oxygen, and it may be exploded by a like electrical current, and reconverted into water. If two tubes are employed, and one placed over each wire, the gases are obtained in a separate state, and in those exact proportions which go to form water. If the water is very slightly acidulated, its conducting power is increased, and the decomposition goes on with much greater energy; the hydrogen gas always appearing at the negative pole, and oxygen at the positive. A similar attractive power is exhibited for one class of bodies by one pole, while a different class are attracted by the other. The *poles* of a battery have been aptly described by Faraday as the doors by which the electricity enters into, or passes out of, the substance suffering decomposition; and in every instance one element of a compound, undergoing electro-chemical change, is found at that point through which the electricity is flowing into the mass, and the other element as constantly gathers at that point through which the electricity is passing out. There has been much difficulty in accounting for this. The difficulty will be more evident if we take the experiment on a large scale: for example, if on one side of a wide river the positive pole is placed in the water, and the negative pole on the other, we shall still have—the battery being of sufficient power—oxygen given off on one side of the river, while hydrogen only would be evolved at the other. Since we know that every particle of water is composed of oxygen and hydrogen in the exact ratio of two measures of the latter to one of the former, it might be supposed that the electric current having separated the oxygen at one point, hydrogen would, having lost its combining element, also escape at the same point, which is not the case. The arrangement of the particles constituting a layer or line of water, howsoever wide, would be as follows:—

P.—O.H., O.H., O.H., O.H., O.H., O.H.—*N.*

If the positive pole is placed on the left, and the negative to the right, oxygen passes off from the first, and hydrogen from the last; if we reverse the poles, the order of the decomposition is changed also. We are not to suppose that when H. is liberated from O. at *N.*, that the O. of that particle passes over along the line to *P.* Water is an aggregation of particles, but those aggregated particles form a complete whole; the ocean is one large drop combined from an infinity of smaller ones. We have already stated that the quantity of electricity which decomposes a body, is exactly equal to that which effects its composition; therefore, where there is continuity, when we disturb the electricity of combination on one side by adding force, it is equalized by passing off on the other. In passing from a solid to a fluid conductor, or from a fluid to a solid conductor, the resistance is very great; but, in overcoming this resistance, on either side, decomposition is produced, as if from one drop,—the hydrogen evolved on one side of the river being in exact ratio to the oxygen liberated on the other, and both are in direct relation to the quantity of electricity in progress. The difficulty which really besets the question arises from the imperfect views which are entertained of the molecular constitution of matter, and of the mode in which the physical forces are distributed around every mass, and each particle of the mass. By learning to regard every combination as a unity,—a complete whole,—the uncertainty of the problem appears to be considerably diminished. Accordingly as bodies appear at the one or the other point of electrical progression,—the point from which it flows out, or that at which it flows in,—tables have been constructed, arranging all substances into positive or negative elements.

NEGATIVE ELECTRICS.	POSITIVE ELECTRICS.
Oxygen.	Hydrogen.
Sulphur.	Potassium.
Nitrogen.	Sodium.
Chlorine.	Lithium.
Iodine.	Barium.
Bromine.	Strontium.
Fluorine.	Iron.
Phosphorus.	Lead.
Selenium, &c.	Tin.
	Bismuth.
	Mercury.
	Gold, &c.

Considerable difficulty arises, however, in these arrangements, since a substance may possess one kind of electrical energy in regard to some bodies, and an opposite energy in relation to others. Oxygen is negative in every combination, and potassium appears to be uniformly positive. Hydrogen is highly positive when compared with oxygen and chlorine, but with metals it always exhibits negative electrical energy. The application of electro-chemical decomposition in the process of the electrotype, will afford a sufficient explanation of the phenomena which attend the chemical influences of the voltaic energy.

Electro-metallurgy, as the process is commonly called, was first made known to the world by Jacobi, of St. Petersburg, and Mr. Spencer, of Liverpool; the origin, however, of the process may probably be referred to Daniell's battery. The cupreous salt in the copper cell is slowly reduced, and when the coating of metal has been removed, it has been found to preserve the most perfect representations of the surfaces upon which it has been deposited.

The most simple form of an electrotype apparatus is represented in Fig. 161. In a glass jar is placed a saturated solution of sulphate of copper; a glass cylinder (a lamp-glass for example) has a piece of strong brown paper or a piece of bladder tied firmly over one end, and this being filled with

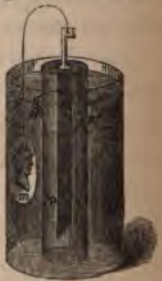


Fig. 161.

diluted sulphuric acid, is placed in the solution of the copper salt. We will suppose it is desired to obtain a copy of a bronze medal :—A piece of copper wire is firmly secured around its edge, and at the other extremity is fixed a plate of zinc; the zinc is dipped into the inner cell containing the weak acid, and the medal into the solution of sulphate of copper. It will be evident that all we have done in this arrangement is to make a compound voltaic cell,—a zinc and a copper plate being in dissimilar solutions. Chemical action takes place on the zinc: this awakening, as is already explained, electrical excitement, the disturbance is passed by the wire to the copper plate, and from every surface of the medal it escapes into the copper solution, and through the interposed diaphragm back again to the zinc. Now, since the electricity which decomposes is exactly equivalent to that by which the stability of composition is maintained, we have, for every equivalent of zinc dissolved, an equivalent of copper precipitated; or for every thirty-two and a half grains of zinc combined thirty-one and a half grains of copper are deposited.

Under whatever arrangement we may effect the electrotype, it must be remembered that the cell in which decomposition takes place, forms but a supplementary cell to the battery employed. The decomposing cell (Fig. 162) is merely a vessel containing the solution, the decomposition of which is desired—for example, sulphate of copper. A fac-simile being required of an engraved copper plate, the engraved plate on which the precipitation is to take

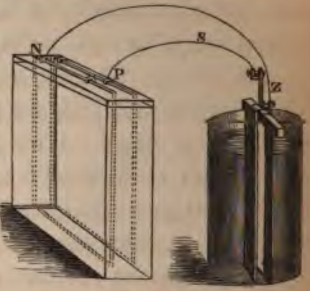


Fig. 162.

place, is connected with the zinc plate of the battery, while a sheet of copper is connected with the copper, silver, or platinum, accordingly as the battery to be employed may be Daniell's, Smee's, or Grove's. As soon as the action commences, water is decomposed, oxygen passes to the positive plate and oxidizes it, and the hydrogen accumulates on the engraved negative plate: by the agency of this hydrogen, the oxide of copper, combined with sulphuric acid to form the sulphate, is reduced; its oxygen forms water, with the hydrogen; and the metallic copper is deposited in the most uniform manner, a perfectly coherent mass, on the engraved plate, of which an exact copy, *in relief*, is obtained. To procure a fac-simile of the original plate, this electrotype is subjected to a repetition of the process, the result of which is, that a reverse impression of it is obtained. The process of electro-plating, with either silver or gold, is in every respect the same in principle, the solutions of the metallic oxides being, however, alkaline instead of acid.

Numerous modifications of these processes have been introduced; but for an account of them, the reader is referred to works which treat especially of the electrotype, electro-metallurgy, or galvano-plastic, as the process is variously termed.

It will be readily conceived, after what has been stated, that in voltaic electricity we possess an agent by which we are enabled to break up the strongest affinities. All the metallic and earthy compounds can thus be resolved into their simpler parts, and in many of the reductions most striking phenomena present themselves.

Among the most remarkable may be named the transmission of the decomposed elements through substances which are bad conductors, and through liquids which have a chemical affinity for them.

The following experiment affords a very beautiful illustration of the first of these conditions, and also gives us the means of repeating in the laboratory many of those processes which are evidently progressing on a large scale in nature. An oblong box (Fig. 163) is divided in the centre by a wall of clay, *c*, three or four inches in thickness, or by a mass of plaster of Paris, or even of sandstone; a zinc and a copper plate, *a*, *b*, connected by a band of copper, is then to be placed on either side of the wall, and the voltaic pair excited by dilute sulphuric acid on the zinc side, and a solution of sulphate of copper on the side of the copper plate. If this simple arrangement is allowed to work for about six weeks, it will be found that the condition of the substance employed as the wall is very curiously changed. On the

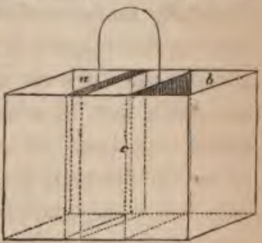


Fig. 163.

side next the zinc plate it assumes a slaty structure; and the copper dissolved in the negative cell, passing with the returning current, will be found in the clay or plaster, arranged in a well-defined line, imitating the character of such mineral lodes as are foundin the primary rocks.

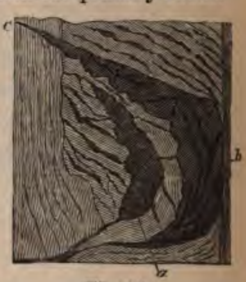


Fig. 164.

Fig. 164 represents the result obtained after the action of a weak voltaic current passing through a considerable mass of clay for several months, which merits some particular description from its perfect imitation of natural phenomena. The mass of Stourbridge clay was placed in precisely similar conditions to those already described, excepting that common salt was employed in the place of sulphuric acid. On the zinc side, *c*, to the depth of an inch and a half, there were distinct lines of lamination parallel to the plate, not extending in straight lines from the top to the bottom of the mass (which was twelve inches deep), but, after proceeding about six inches down, exhibiting a tendency to bend inwards. Upon breaking the clay open when dry, it was found that after proceeding towards the centre of the mass they again turned outwards, and formed, indeed, curved lines from one point near the middle of the zinc plate to its lowest point. A consolidation on the copper side was very distinctly marked, and the appearance was that of a continuation of hard nodular masses along the lines of the returning voltaic current. This consolidation had evidently been produced by drawing the particles from the middle of the mass, where a large hollow, *a*, was formed, and this was found to be a portion of a very decidedly marked line of action from the bottom of the zinc plate to the centre of the copper plate, *b*, and from that point to the top or the positive side. As these curved lines approached the zincous side, they were crossed and split by laminations, although very distinctly continued. We have thus evidence afforded us of two distinct lines of power along which the particles arrange themselves. It was found that the curved lines were formed by fine strings of copper. From near the top of the zinc plate a band of metallic copper and its oxide, with here and there some lines of the carbonate of that metal, was formed, describing a line inclining from the horizontal at an angle of about 40°. When it approached the copper plate, it was gradually bent back, and formed a curve towards the bottom of the mass on the zinc side. Mr. Robert Fox, who first observed these very curious results, says, the general laminated character of the clay appears to indicate that a series of voltaic poles are produced through it, the symmetrical arrangement of which had a corresponding effect on the structure of the mass.

We may, however, show very strikingly the passage of metallic bodies through walls of clay, by a very easy experiment. Let a decomposing cell be divided by such a wall, and place a metal plate to be gilded in a solution of common salt on one side of the partition, and the alkaline solution of gold on the other, a plate of gold or a platinum wire being placed in it, and both connected with the battery. The gold will now pass through the wall of clay, and be deposited on the plate in the same manner as it would have done had no such obstacle been placed in the path of the current.

The passage of the decompounded principles of any body through solutions which have a strong chemical affinity for them may be examined as follows:—Take three wine-glasses: in the first place sulphate of soda, in the second a solution of blue litmus, in the third pure water; place the wire connected with the positive pole of the battery in the water, and the negative wire in the sulphate of soda; connect the glasses by fibres of cotton dipping into the solutions. The sulphuric acid will accumulate at the positive pole—to do which it must have passed through the solution of litmus, the most delicate test for the presence of an acid,—and yet no change in its colour is produced. If we reverse the order, and employ as delicate a test for the presence of an alkali, it will be found that the soda will pass through it, and along the moistened cotton, without producing any change. Even sulphuric acid can thus be passed through ammonia, and this volatile alkali through muriatic acid, without combining, so completely is the power of chemical affinity suspended while the element is in this transition state.

Berzelius has given a very easy method for effecting the decomposition of alkalies by the agency of a voltaic current. A concentrated solution of caustic potash is poured on some mercury, a little potash remaining undissolved in the solution over the mercury; the negative wire is then connected with the metal, and the positive one with the alkaline lye, both being of platinum: in a very short time the mercury will become thicker, and metallic crystals of the amalgam of mercury and potassium will form.

A curious amalgam of ammonia may be produced in the same manner, by employing a strong solution of sal ammoniac instead of potash. After a very short action the mercury will begin to swell up, until it at last attains six or seven times its original size; assumes a brilliant whiteness, and, creeping up the wire, eventually floats in the solution. It was the formation of this amalgam which led Sir Humphry Davy to think that ammonia, like the other alkalies, had a metallic base. Ammonia is a compound of hydrogen and nitrogen gases; therefore, if metallic, one of these gases must be a metal; and, from the peculiar chemical characters of hydrogen, the probability is that that highly attenuated body may ultimately be proved to belong to the metallic class.

A very pleasing set of experiments, connected with this agency, are the production of certain coloured images on polished plates of platina, silver, or steel, which have been called *Nobili's electro-chemical figures*. They are best produced from solutions of the acetate of lead, sulphate of copper, and chlorate of manganese, in the following manner. Place a polished steel plate in a solution of the acetate of lead, and upon that a card with a regular pattern cut out; a circle of wood should be placed on the card, so as to stand a little above it, and a disc of copper over all: contact is made with a battery of three or four cells, and maintained for a quarter of an hour, the steel being connected with the negative, and the copper with the positive, pole of the battery. On removing the steel, it will be found that the pattern of the card is represented on it in the most beautiful manner, every prismatic colour being reflected as we hold the steel plate at different angles to the light, by the film of the peroxide of lead deposited upon its surface.

The experiments of Becquerel and Crosse have proved that under the influence of exceedingly weak voltaic currents, decompositions of the most remarkable kinds may be effected, and the crystallization of the metals and many of the earths accomplished. In nature, results which are referable only to electrical influence obtain. In most of our mineral deposits it will be found that a remarkable regularity in the line of direction prevails, and in many cases the metalliferous deposits in the mineral veins are found to have a regularity and order which can only be explained on the principle of electro-chemical deposit. It is curious, also, that the condition of the rocks materially influences the character of the mineral deposits, and that the great accumulations, particularly of copper ore, are always found near the junction of the granite and of the clay-slate rocks. These rocks are not very dissimilar in their chemical composition, but they differ considerably in their physical constitution, and it has been found, by very carefully conducted observations, that they always differ in temperature at every depth from the surface. This may be sufficient to produce *thermo-electric currents,* to the phenomena of which attention must now be directed.

If one end of a long bar of iron is made hot in a spirit-lamp or a fire, and the other end is kept cold by the application of water or ice, the equilibrium of the bar is disturbed and electric progression established. If wires are connected with each end of the bar, and the circuit made up through a galvanometer, the deflection of the needle will prove the circulation of electricity. When two metals, having different conducting powers of heat, are united, and warmed at the united end, the current is more powerful. The most active thermo-electric combination is, however, that of the more crystalline metals, bismuth and antimony. The following table exhibits the relation of several metals to each other, in reference to their power of being thermo-electrically excited :—

Positive. + Bismuth.
Platinum.
Mercury.
Tin.
Gold.

Silver.
Copper.
Zinc.
Iron.
Negative. — Antimony.

Those metals which are most remote from each c being the most suitable combinations for produ thermo-electricity.

Seebeck, of Berlin, first noticed these currents gener by heat, and they have since been very extensively stu by Professor Cumming, the late Mr. Sturgeon, Mr. deaux, and others. The result of their investiga has been to prove that an unequal application of gives rise to electrical disturbance. A very pretty ex ment, showing the excitation of electric currents by has been devised by Professor Cumming. A pie copper wire is bent into the form *a a* (Fig. 165), and its two extremities connected by a piece of thin platinum wire, *p*; if the flame of a spirit-lamp is applied to one of the junctures, and a magnet, M, is held near one of the vertical arms, attraction and repulsion will be detected, according to the direction of the current. Bismuth and anti are the most powerful thermo-electrics; if two small are tied together at one end, the others being sepa

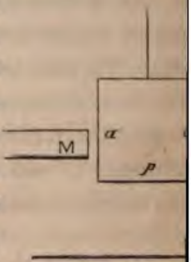


Fig. 165.

about an inch, and connected by wires with a galvanometer, the smallest increment of heat can be detected. By holding such a pair between the finger and thumb, every variation of temperature which takes place in the body may be measured. By a combination of these metals soldered together in pairs, a *thermo-electric multiplier* is formed, which exceeds in delicacy every other kind of instrument devised for measuring thermic action: with such an instrument the discovery of the polarization of heat was made. By thermo-electric currents, although these are of low tension, chemical decomposition has been effected, magnetism produced, physiological effects shown, and the electric spark evolved; proving, therefore, their identity with the other forms of electricity.

Dr. Andrews has shown that platinum wires, connected with salts in a state of fusion, generate electric currents of this character. Indeed, it appears impossible to change the temperature of any body without exciting Electricity.

MAGNETISM is, perhaps, the most remarkable of the modifications of electricity, and, connected as it is with great terrestrial phenomena, of the highest interest.

At Magnesia, in Lydia, the native loadstone was first discovered, and hence called μάγνης (*magnes*), which we may regard as the origin of our modern name—the *magnet*.

Magnetic iron—loadstone—is found in all parts of the world. It is an ore of iron, containing 73 parts of the metal and 27 of oxygen, usually combined in two states of oxidation, the black and the red. If a piece of this stone is freely suspended by a thread, and left free to take its own position, it will arrange itself so that its extremities point towards the north and south poles of the earth, and those ends will be found to be attractive to light pieces of iron, which become themselves magnetic by contact.

This property of communicating magnetic power enables us to *charge* bars of iron or steel, and thus greatly increase the force, which is comparatively weak in the natural stones. Yet they have been found of considerable power. Sir Isaac Newton wore a small loadstone set in a ring, which is said to have been capable of lifting 746 grains, or 250 times its own weight; and Cavallo informs us that he saw a natural magnet, which weighed 6½ grains, which lifted 300 grains. It is usual to mount loadstones in a frame of iron, by which a more decided termination is given to its poles, and its attractive power increased. If a piece of steel is brought into contact with a natural magnet, the same qualities—polarity and the power of attracting iron—are imparted to it.

The laws of this attraction require careful study before the phenomena of magnetism can be appreciated.

Every piece of soft iron brought *near* a magnet becomes, by induction, itself magnetic. The following simple experiment fully illustrates this. A (Fig. 166) is a magnet; K, a key, is held near one end of it:—while in proximity the key is a magnet, and if N, a nail, is brought in contact with it, the attractive force will be found sufficient to hold it attached; if, now, the magnet is removed, the nail will fall. This is in principle precisely similar to the attraction of iron filings by a magnet when it is passed over them. Holding a bar magnet some little space above the filings, they start up and cling to it; upon examining the bunch of filings they will be found to have arranged themselves in curved lines. These curves are, however, better illustrated by a larger experiment. If over the two poles of a magnet bent into a horse-shoe form, a piece of paper, stretched on a frame, is placed, and iron filings are sprinkled, they arrange themselves into a beautiful system of curved lines (Fig. 167). Every particle of iron has, by induction, become a magnet, and it attracts by its north pole the

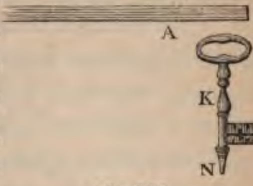


Fig. 166.

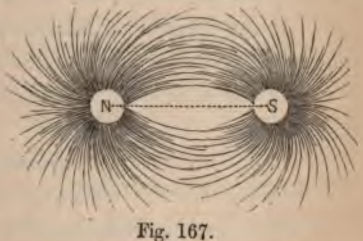


Fig. 167.

south pole of the particle nearest to it, that south pole attracting the next and determining its north pole, thus:—

N—S—N—S—N—S—N—S.

In this experiment every particle of iron attracts its neighbour, and when a bar of iron is placed upon a magnet it adds to its power;—it re-acts on the magnet which induces its magnetism, and increases its magnetic intensity. This is proved by having a bar of iron placed on the poles of a natural magnet, when it will be found to support a larger weight than before; and it is upon the same principle that we are enabled to add to the weight which a magnet will at any time support if it is increased slowly and in small quantities. The phenomenon of magnetic repulsion is best shown by hanging two bar magnets so that their two north or their two south poles can be freely moved. Upon attempting to bring the two similar poles together, it will be felt that a force prevents this. If two magnets of different strengths are used for the experiment, the influence of the more powerful magnet will alter the polarity of the weaker one, and attraction will ensue.

Numerous manipulatory processes have been employed and recommended for rendering iron or steel magnetic. Iron, under certain circumstances of position, is rendered magnetic by the inductive action of the earth's magnetism. Nearly all iron palisades, and the vertical bars of windows, will be found to be magnetic, and similar bars are very readily rendered so by artificial methods.

It is necessary, before stating those, to describe the difference between a body which is in a magnetic condition, and one which is not. A non-magnetic bar of iron will not attract or gather up iron filings, and, if presented towards a compass-needle delicately suspended, it will attract it equally with either end. The bar has no *polarity*. If we make it magnetic, it will gather up fine dust of iron, and when presented to a compass-needle, it will *attract* it with one end, but *repel* it with the other. It has acquired polarity.

If a bar of iron, such as a kitchen poker, which has been found to be devoid of magnetism, is placed with one end on the ground, slightly inclined towards the north, and then struck one smart blow with a hammer upon the upper end, it will acquire polarity, and exhibit the attractive and repellent properties of a magnet.

Soft iron, although it readily receives magnetism, does not retain it; we have, therefore, recourse to steel for the construction of permanent magnets. Bars of steel may be saturated with magnetism, and, under proper circumstances, made to retain it for any period. Some of the methods by which this is effected must now be described.

Mr. Canton's process of making magnets without the aid of natural loadstones or other artificial magnets, as proving a very curious condition of this agency in its state of terrestrial magnetism, deserves the first consideration. He recommends that six bars of soft, and six of hard steel should be taken, the latter being the largest.

All the bars are to be marked at one end; an old iron poker is placed nearly upright, as in Fig. 168, and, by means of a piece of silk, one of the bars of soft steel is held against it, near the top. With the other hand grasp a pair of tongs a little below the middle, and, keeping them nearly in a vertical line, let the little bar be rubbed with the lower end of the tongs from its marked end upwards, about ten times on each side. By the slight molecular disturbance thus produced magnetism has been derived from the earth, and the little bar will be found to have sufficient attractive force to support a small piece of iron. When four of the soft bars are thus rendered magnetic, the other two must be placed a little distance from, but parallel to, each other, having their marked ends at opposite sides, and connected by two pieces of soft iron. The magnetized bars are placed in pairs, and with a small piece of wood between each pair; they are rested in the middle of the unmagnetized bar, and brought to touch at the top. They are then slid four or five times to and fro the whole length of the bar; and this bar being magnetized, it is changed for another, which is treated in a similar manner, and so on until all the bars are duly magnetized; with these soft bar magnets the

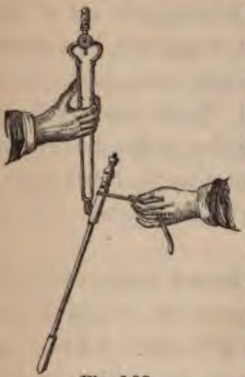


Fig. 168.

same process is repeated over the hard bars, which, retaining their magnetism permanently, form the series we require.

Duhamel's method of magnetizing steel bars is shown in Fig. 169. The bars B B are placed parallel to each other, and their ends are united by two pieces of soft iron, M *m*. Two bundles of steel already magnetized, A, A, with all similar poles together, are inclined 45° to the bar B, and then separated from each other,—this being repeated several times on one bar; the same process is adopted on the other, until the two bars are saturated with magnetism.

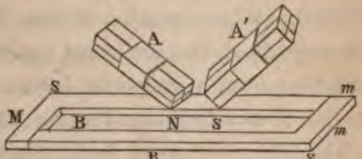


Fig. 169.

Magnets which are bent into the form shown at Figs. 170 and 171 are the most convenient for general use;—they are called *horse-shoe magnets.* To prepare those, a single bar, bent of the required form, is placed as shown in the woodcut, with a piece of soft iron M across the poles, and magnetized according to the method already described, developing the magnetism in both arms

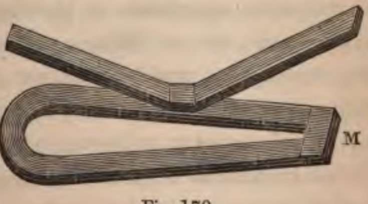


Fig. 170.

of the bar, by repeatedly passing along them the permanent bar magnets. The method of placing a small piece of soft iron between the two bars, as recommended by Epinus, is sometimes adopted. When a number of these bars are magnetized, they are bound together, and thus form a compound horse-shoe magnet of considerable power (Fig. 171).

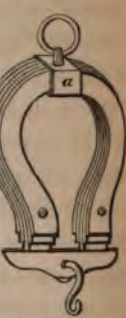


Fig. 171.

The process employed by Dr. Knight, for forming artificial magnets of an iron paste, as we learn from a communication made to the Royal Society by Mr. Benjamin Wilson, after Dr. Knight's death, was as follows:—Metallic iron, in the finest state of division to which it could be brought by mechanical means, was made into a paste with drying linseed oil, and, having been moulded into the required form, baked at a low temperature, and then magnetized. The power of these bars is stated to have been very remarkable. It is an instructive experiment to place in a glass tube, open at both ends, fine steel-filings, so packing them that they may retain their positions without any covering at the ends. Such arrangements may be magnetized by passing a powerful magnet up and down on the outside of the glass. In this example, as in the case of Knight's magnets, every particle of the powder becomes a small magnet, and the accumulated power of the whole acts from the extremities, which are in opposite states of polarity. Similar condi-

, of course, supposed to prevail in solid steel l it is to the differences in the molecular arrange- he metallic particles, that we must refer the varia- power of absorbing and retaining magnetism ferent kinds of steel are found to exhibit.

oresby, who has devoted much of his attention henomena of magnetic induction, recommends iod of Dr. Gowan Knight for magnetizing the and plates, which he considers superior to thick compound magnets. Two bar magnets of the power are placed in a straight line, with their poles near each other. Upon these, the bar to ietized is laid, and the magnets drawn asunder ite directions, until the bar rests with its two es upon the ends of the magnets. It is allowed n for a short time in this position, then slid 'ays, and turned over, so that another side rests nagnets, taking care to maintain the same direc- ıe poles.

fting or sustaining power of magnets varies very y; the most powerful, however, are those which ly been made by Logeman, of Haerlem, after a pro- yet published, devised by Elias: these are capable ning twenty-six times their own weight. It is not ole but the process by which these magnets are volves the use of the voltaic battery. I have found l bars brought to a tempering heat, and placed in a copper wire connected with a voltaic battery, and then plunged into cold water, or, still better, into a solution of the yellow prussiate of potash, become most powerfully magnetic. This mode of inducing magnetism will be more fully described when we come to the consideration of *electro-magnetism.*

In all magnetic arrangements, the laws deduced by Hansteen appear to be correct expressions of the facts observed.—

1. The attractive and repulsive force with which two magnetic particles affect each other, is always directly as their intensities, and inversely as the squares of their mutual distances.

2. The absolute intensity of any magnetic particle, situated in the axis, is proportional to the square of its distance from the middle point of the axis.

3. The distance from the middle of a magnet being the same, the force opposite the poles, or in the direction of the axis, is double of the force in the magnetic equator.

In all cases the south pole of a magnet will be found to be weaker than the north pole.

A few examples of experiments which can be readily repeated, will most sufficiently place the general phenomena of magnetism fairly under consideration.

We take a magnetized bar, and break it in several pieces; every piece will be found to be a magnet, and those ends north and south, which tended towards the north and south extremities of the original bar. By this we prove the equal distribution of the force along the bar; the only variation which can occur, being that which may arise from any unequal density of the mass of the metal.

If the weight which any magnetized bar will sustain is accurately ascertained, and then another bar be fully magnetized with this one, it will be found, that, although the second bar has acquired a considerable degree of magnetism, the original bar has lost none of its sustaining power. The only rational deduction which we can make is, that one magnet has been the channel through which the electrical influences that determine a magnetic condition pass to and magnetize a steel bar.

If a magnet is loaded with the full weight which it will support, and this be suddenly broken off, it will be found that the magnet has lost very much of its power. But if we attach a small weight to it, and then gradually increase it, we may restore the original power.

If we hang at the end of a bar magnet a weight which is nearly as much as it will support, and then bring another magnet near to the end to which the weight is attached, it will fall off. The attractive force has been interfered with by the second magnet; probably the disturbance has induced opposite polarity in the particles nearest to the second bar.

Supposing any number of bars of steel are magnetized to saturation, and that each of them separately sustain a weight which is represented by 10, it will be found, upon uniting any number of them in a bundle, that the force will not be a multiple of the weight supported by each bar.

Coulomb determined the difference by his torsion balance; the result given by him being

1 Magnet	82
2 Magnets united	125
4 Magnets united	150
6 Magnets united	172
8 Magnets united	182

We are led to believe that when two north poles are placed together, a re-arrangement of polarities takes place; and that hence the loss of power resulting from combination. It has been found that the outer magnets of a bundle are more powerfully magnetic than those within; that a single magnet of the same mass and weight as a compound one, is capable of receiving nearly as much magnetism. From this it may be inferred that the magnetic force, or principle, has a tendency to arrange itself mainly over the surfaces of bodies.

These facts, and the constant appearance of dissimilar poles, have led to the adoption of a theory of the existence of two kinds of magnetism; this, however, is precisely the same as the positive and negative of electricians, and it is believed all similar phenomena may be explained by the assumption of one kind only, the apparent difference being merely a difference in the direction of the action of the force.

That magnetic polarities may be induced along certain nes on steel plates, is shown by the pleasing experiments . Haldat. If we take a steel plate, and with the north ole of a bar magnet trace any figures, south polarity ill be induced along those lines. If, now, steel filings re shaken upon the plate, they will arrange themselves the empty spaces between the lines which have been raced by the magnet; the figures being represented by he uncovered steel. These figures will remain for many onths upon these plates; but if the steel is heated, it radually loses its magnetism, and returns to its original tate. M. Haldat renders them permanent by covering he steel with a varnish, after the figures have been traced y the magnet, and before the iron filings are dusted on t. If carefully sifted, they arrange themselves in the sual manner, and as the varnish hardens they are involved and retained in their positions in the indurated ass.

There are but a few metals which have the magnetic haracter of iron. Cavallo was the earliest experimentalist ho appears to have directed attention to this examination; iot, Becquerel, Sturgeon, and others, have continued he investigation. Faraday's researches are by far the ost perfect; he has determined that all the following odies have a magnetic character: that is, that they are usceptible of receiving the same kind of polarity as iron, ut none of them to the same degree. In this list they re arranged according to their disposition to receive agnetic influence.

Iron.
Nickel.
Cobalt.
Manganese.
Chromium.
Cerium.
Titanium.
Palladium.
Platinum.
Osmium.

Neither copper nor zinc occur in this list, but their compound, *brass*, was found by Cavallo, under certain conditions, to be magnetic. This character is most remarkably shown when the brass has been hardened by hammering. Delicate magnetic needles are sometimes influenced by the magnetism of the brass case in which they are mounted; therefore our most intelligent instrument-makers reject hammered brass in all delicate instruments, and use such only which has been carefully cast. Sturgeon thought he had detected magnetism in some other metallic compounds, the separate elements of which were not magnetic. On the contrary, it appears that antimony lessens the polarity of iron, and that arsenic destroys the magnetism of nickel.

Since 1802, numerous experiments have been made for the purpose of determining if there was any truth in a theory advanced by Cavallo, that all bodies in nature were susceptible of magnetic influence. By a careful examination of all that has been done since that period, by Coulomb, Biot, Sage, Guyton, Haüy, Becquerel, and others, the inevitable conviction has been, that although indications of a new form of magnetic force have been occasionally obtained, no clear views of the phenomena have been obtained by any of these experimentalists.

To Faraday is undoubtedly due the development of that magnetic condition which is now known as *dia-magnetism*. This term means no more than this :—All bodies, such as glass, which allow magnetism to permeate them freely, are called dia-magnetic—from *dia*, a way,—and hence, all the bodies in nature are now grouped under the two classes of magnetic and dia-magnetic. That a clear impression may be made on the mind, as to the difference between these conditions, it is necessary to explain them somewhat minutely. If a bar of iron is suspended, free to move in any direction, between the poles, N, S, of a magnet (Fig. 172), the bar will arrange itself along a line which will unite the two poles: it places itself in the *axial line*, or along the *line of force*. Such is the condition of a magnetic body. If a substance of the dia-magnetic class is placed in the same situation,—as, for example, a bar of bismuth,—between the poles N, S (Fig. 173), it places itself across, or at right angles to, the axial line. The magnetic body is attracted by each pole, but the dia-magnetic body is equally repelled by either pole. Magnetism may be regarded as an attractive force, dia-magnetism as a repelling one. By referring to Fig. 167, and contrasting it with Fig. 174, on the next page, the difference between these two modes of force will be understood. The curves formed by dust or filings of a magnetic body pass from one pole to the other; those, on the con-

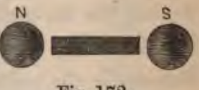


Fig. 172.

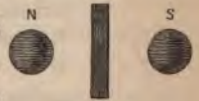


Fig. 173.

trary, which are produced by a dia-magnetic substance, bend from the poles,—they are repelled in every direction. Among the dia-magnetic metals, the most remarkable are the following, which have been arranged by Professor Faraday in the order of their intensity.

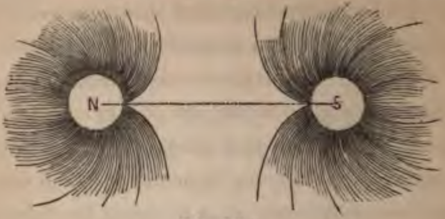


Fig. 174.

Bismuth.
Antimony.
Zinc.
Tin.
Cadmium.
Sodium.
Mercury.
Lead.
Silver.
Copper.
Gold.
Arsenic.
Uranium.
Rhodium.
Iridium.
Tungsten.

To this list may be added most rocks which are not ferruginous, and by far the largest number of substances belonging to the vegetable and animal kingdoms.

These forms of electricity—for every experiment appears to determine them to be so—may be regarded as the great agents at work in nature, determining the structure and arrangement of masses. The influence of voltaic electricity, when acting upon clays, &c., has been already mentioned; an extensive series of experiments, of another character,

ar to prove that particles of matter free to move are
usly influenced by magnetism, obeying one of those
itions which have been just described.

ie result of two experiments will sufficiently illustrate
Fig. 175 represents an electro-magnet (a form of
iet to be described more fully in a future page), so
d that a glass plate may be laid upon its poles. An
ig of wax, or plaster, being
d around the glass, it is
ered capable of holding
s. Such being the dispo-
i of things, and the electro-
iet being rendered power-
magnetic, a warm and
y saturated solution of the
sulphate of iron was
ed into the dish. Upon
ng, the salt crystallizes, and the crystals arrange them-
s in true magne-
der. Fig. 176 is a
from a plate upon
h crystals had
formed. Along
xial line between
wo poles they had
ed abundantly,
the crystals also arranged themselves in two well-
ed lines extending in curves from one pole towards

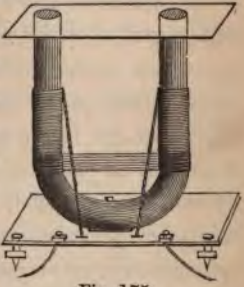


Fig. 175.

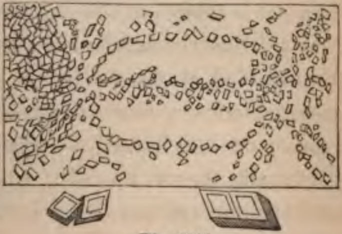


Fig. 176.

the other; and beyond these, several other lines, having still a curvilinear character, were to be detected.

Crystals of sulphate of iron, forming under ordinary circumstances, unite by their faces; but when the crystallization takes place within the influence of magnetism, they unite in a different manner. Sulphate of iron crystallizes in oblong rhombic prisms, and when forming as in the experiment just described, they arrange themselves, with regard to each other, so that the acute angle of one crystal unites with one of the faces near to, but never actually at, the obtuse angle of another. This is shown, in the larger pairs of crystals beneath the arrangement on the plate, in the last woodcut. If the crystallization is very rapid, this kind of arrangement does not occur, the mechanical force of crystallization is sufficient to overcome even the magnetic power; but if the crystals form slowly, the lines of magnetic force are well defined.

If the crystallization of any substance of a dia-magnetic character is allowed to take place under similar conditions, a very different result is obtained. An experiment of the following character readily determines this. Pour upon the glass plate a solution of nitrate of silver, and carefully place over each pole, N, S, a globule of mercury. The result of this is the formation of the *Arbor*

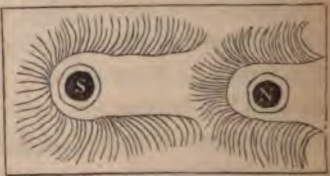


Fig. 177.

Dianæ, or silver tree; and under ordinary circumstances the crystallization of the silver will commence in connection with the globules of mercury. Under magnetic influence the effect shown in Fig. 177 is produced. The globule of mercury—this metal being itself dia-magnetic—is spread out over the poles; and two singular curves, first forming at some distance from the poles, a series of fine lines of crystallized metallic silver, shoot off nearly at right angles to those lines, which are those of magnetic attraction.

From these results, and the numerous experiments of Faraday, Plucker, and others, it appears to be proved beyond all doubt, that magnetism is universal,—that every form of matter is susceptible of one or the other magnetic condition. The number which are magnetic, *as iron is*, are exceedingly few; those which belong to the dia-magnetic, or *bismuth-like* class, are most extensive.

It has been found, that if a polarized ray of light is passed along a piece of dense glass, so placed, that it can be brought under magnetic influence without being disturbed, the ray is deflected, or bent out of its true path, by magnetism. It was therefore inferred that light was influenced by magnetism; but it appears that the effect is due to molecular alteration in the medium through which the light passes. Through dense glass, the effect is decided; through pure water, the deflection is very trifling, but it is increased when salts are dissolved in it; and when the experiment is tried with air, no effect is produced. A medium is necessary: the more dense, the greater is the deflection produced by magnetism; therefore the bending of the ray is due to the medium, and not to the magnetism acting directly on the line of light.

It has long been known that powerful electric discharges would affect the magnetic needle; Beccaria, Franklin, Wilson, and others, having studied some of these phenomena; but the only determination to which they came, was, that electricity acted upon the needle as a mere mechanical force. In 1820 Professor Œrsted, of Copenhagen, discovered that a current of electricity circulating along a wire produced a deviation of a magnetic needle. Thus was opened up a new branch of science, which has been productive of the most important results, adding many new truths to our store, enabling us to penetrate still further into the mysteries of nature, and add to the conveniences of life. If a copper wire is bent into the form of a square, but with the two ends open, and we plunge these two extremities into a mercury cup connected with a galvanic battery, and so place it that the planes of the square are coincident with the planes of the magnetic meridian, a current will circulate along the wire from *a* to *c*, from *c* to *d* horizontally, and descend to *e* and *b*. If the battery is not in action, or if the connection is imperfect, and a magnetic needle held above the wire *c d*, it will remain parallel with the wire;

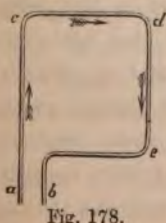


Fig. 178.

but the moment a current circulates, the needle will move, and deviate to the east and west of the magnetic meridian; the direction of the magnetic poles being altered when the line of the current is changed. Such was the original experiment of Œrsted; but a bar of magnetic steel, being hung over a wire along which a voltaic current is passing, is always deflected at an angle to that current, the amount of deflection being regulated by the force of the current. The following rule has been given by Ampère, for ascertaining at all times what will be the direction of the deviation:—Let any one suppose himself to be lying on the wire, so that the positive current shall enter at his feet and pass out at his head, and, looking at the needle, its north pole will move towards the right hand; if the direction of the current is altered, the north pole will deviate to the left.

If, while a current is circulating along a copper wire, some steel-filings are brought near it, they will be attracted by it, and cling to the wire as to a magnet; if the current is interrupted, they will immediately fall off. This is a simple but convincing proof of the magnetic character of the electric current.

From the discovery of this deviation of a magnet across the line of an electric current, Schweigger constructed the galvanometer, or measurer of electric currents. The galvanometer is of very simple arrangement. If a considerable length of copper wire, clothed with silk or varnished, is wound around the hand, and the hand be then drawn out, we shall have the lines of wire on the top and bottom lying parallel to each other, and if connected by its ends with a battery, the current would circulate through it; in one direction in the lower, and in another direction in the upper part of the coil. Now here, instead of moving along one length of wire, the current circulates along a hundred lengths, and we have a hundred times greater intensity; consequently, a magnetic needle is more readily moved by a weak voltaic action.

Nobili's galvanometer is the most perfect, and, however modified, is still the form of instrument usually employed in delicate investigations. It will be understood that in every multiplier of this sort, two forces are in action—the force of the earth's magnetism, holding the magnet in the polar direction, and the force of the current in the wires, acting in opposition to this; therefore, unless the latter is more powerful than the former, the magnetic needle is not moved. In Nobili's instrument the directive power of the earth is annulled, this being effected by the *astatic* needle, or a compound needle with its poles, A, B (Fig. 179), reversed. One of these needles is suspended so as to hang between the coil of wire, and the other just above it; consequently, as the influence of the earth is almost entirely removed, and the force of the current in the two parts of the coil is equally acting

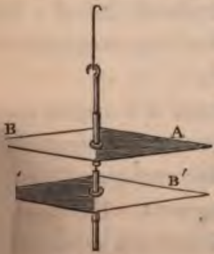


Fig. 179.

on the needles, the sensibility of the galvanometer is greatly increased. This will be readily understood by reference to Fig. 180, in which a galvanometer is shown in section. *a* is a brass rod firmly fixed to a base of mahogany *b*; from the rod is suspended the astatic needle *c*, by a fibre of unspun silk; securely attached to the base is the coil of covered copper wire *d*, the two ends hanging free to be connected with any substances under examination, or soldered to two brass cups let into the mahogany base, and filled with mercury, through which the connections can be readily made.

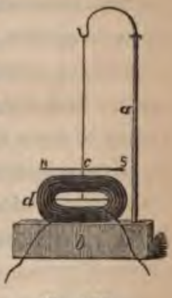


Fig. 180.

Further proof of the magnetic action of the voltaic current is afforded by twisting a copper wire spirally around a glass tube, and placing within it a sewing needle. By connecting the wire with a battery, and allowing the current to traverse the wire for a minute, the needle will be rendered permanently magnetic.

If we twist a considerable length of clothed copper wire around a bar of soft iron, which has no attractive power, and then connect the wires, so that the circuit with the battery is made up by the disturbance circulating along the convolutions, the bar of iron will become most powerfully magnetic. In this way are constructed the most active *electro-magnets*. One having the horse-shoe form is shown in a former figure. With magnets of this kind, it is easy to remove, at pleasure, all magnetic influence from any substance which may be submitted to its action; since, the moment connection is broken with the battery, the current ceases to traverse the wires, and all magnetic attraction terminates. Electro-magnets have been constructed capable of sustaining many tons, and, from the enormous power thus obtained, it has been thought practicable by many to apply it for the purpose of moving machinery.

Having instituted a very extensive series of experiments, with a view of determining the question of the applicability of electro-magnetism as a motive power, I embrace a small portion of space to point out the difficulties, if not impossibilities, which appear to prevent its use within the limits of a reasonable economy.

In the first place, the rate at which the power diminishes through space prevents our obtaining the full force of the magnets. This is shown in the following table:—

The magnet with the armature in contact supports				220	pounds.
„	with the armature	$\frac{1}{250}$	of an inch distant	90·6	„
„	„	$\frac{1}{125}$	„	50·7	„
„	„	$\frac{1}{100}$	„	50·5	„
„	„	$\frac{1}{63}$	„	51·1	„
„	„	$\frac{1}{50}$	„	40·5	„

No machine could be constructed, in which the moving parts could be brought nearer together than the $\frac{1}{50}$ of an inch, this distance being required to meet the expansion of the iron, yet the power lost is enormous.

The best form of magnetic engine which has yet been constructed, is that in which a certain number of electro-magnets have been set upon the periphery of a wheel, and another similar set upon a frame surrounding the wheel, with an adjustment by which the direction of the current, and consequently the poles of the magnets, can be regularly changed; for the point at which the current enters becomes a north pole, and the point of its exit a south pole. Others have been designed, in which one electro-magnet has been made to work in a cylinder, which was also electro-magnetic; and Page's celebrated American machine appears to be constructed on the principle of drawing a core of iron, *a b*, into a helix of copper (Fig. 181). By the reciprocating action of these piston-like temporary magnets, a considerable extent of motion is obtained.

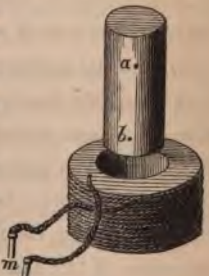


Fig. 181.

The second greatest difficulty to be overcome is, that, notwithstanding the loss of power with distance, a still greater loss takes place with motion. The moment any magnetic body is moved in front of either a permanent, or an electro-magnet, it loses power, and this loss increases very rapidly with the increase of velocity. This obstacle stopped the progress of the very extensive researches of Jacobi, after he had expended upwards of £30,000, granted him for his experiments by the liberality of the Russian Government; and in the report made on Professor

Page's engine, we find that with increase of speed its horse-power is constantly diminishing. By the most careful calculations deduced from my experiments, and from the results obtained by others, I have determined that the economic difference between a steam and an electro-magnetic engine is as follows:—

A grain of coals burnt in the boiler of a Cornish engine, lifted	143lbs. one foot high.
A grain of zinc consumed in a battery to move an electro-magnetic engine, lifted but .	80lbs. one foot high.
The cost of coals is per cwt. not more than	9*d*.
The cost of zinc per cwt. is above . .	216*d*.

Therefore the cost of working an electro-magnetic engine, to do an equal amount of duty to a steam engine, will be more than fifty times greater than it, both being moved with the utmost regard to economy.

An important application of the magnetization of soft iron, has, however, been made in the *electric telegraph*, which is, at once, the most valuable boon of science to the necessities of life, and the most complete illustration of the necessity of cultivating abstract science.

Having already described the galvanometer, reference to that instrument will render the principle of the electric telegraph easily intelligible. Supposing the terminal wires of the galvanometer, as shown in Fig. 180, to be many miles in length—we will suppose them to extend from London to Liverpool;—connection is made with the voltaic battery in London, the galvanometer being at Liverpool, and the needles are deflected, N. being to the right hand of the observer: if the connection is broken, the needle returns to its zero; and if again the wires are connected, but so that the current may pass in an opposite direction, the needle will deviate, but N. will now be to the observer's left hand. Numerous mechanical contrivances have been introduced, many of them of the utmost value in practice, but which it would be out of place to describe in this work. In some arrangements the signals are imparted by means of an electro-magnet, which attracts and repels an armature, the motion of which is communicated to a toothed wheel, moving the index-needle from letter to letter on the dial.

Travelling by railway, we see a number of wires fixed on poles, by being passed through peculiarly shaped stoneware cylinders; these are for the purpose of ensuring the perfect insulation of the wires, since, but for this, the electricity would pass down a damp pole to the earth, and the power of communication be lost. Formerly, one wire conveyed the current from the battery, on one side, to the galvanometer at a distance, through which it passed, and then returned by another wire back to the battery. In 1837, Steinheil showed that the returning half of the wire might be dispensed with, and that the *earth itself* would perform the function of the wire. All that is necessary is, that one short wire from the voltaic battery at one end of a line, and from the galvanometer at the other, should be sunk into the moist earth, and there connected with a mass of conducting metal, from which the electricity passes to complete the necessary closed circuit.

The earth is a reservoir of electricity: it is disturbed at Liverpool by the excitement of the voltaic influence, and its pulsations are communicated at once to London. The idea of any principle passing *along* the telegraph wires must be discarded. A current, as something flowing, conveys a false idea; but we have no other term to express electrical progression. Suppose the telegraph wire to be a tube filled with water, and that one drop more is forced into it at Liverpool, one drop will of course fall out in London: something analogous to this occurs with electricity. In the experiments of Breguet, on the railway between Paris and Rouen, it was determined that the resistance in a circuit of forty miles of wire and forty miles of earth was one-half through the earth to what it was through the wire. Printing telegraphs are constructed upon the principle of causing the electricity to effect chemical decomposition, instead of move a needle. Many compounds are very readily decomposed by voltaic electricity; therefore, a piece of paper is covered with such a composition, and when touched with the wire, the decomposition is effected. Paper covered with a mixture of iodide of potassium and starch is sometimes employed; the electricity decomposes the salt, and a purple iodide of starch is formed, and the letter or sign is printed in this new combination. In other cases paper is saturated with the ferro-prussiate of potash, and kept moist; the terminal wire being of iron, prussian-blue is formed over every point when contact is completed.

Electro-dynamics exhibit many very curious influences, as exerted by electricity in motion—*Currents*. Wires, if free to move, exhibit these in a very interesting manner. *They attract each other when the currents are moving in the same direction, and repel each other when moving in opposite directions.* The action of currents moving in the same direction is shown in Roget's electrical spiral (Fig. 182). A loose coil of thin copper wire is suspended from a metallic pillar; the lower end just touches the surface of some mercury in a cup fixed in the stand, and which communicates with one pole of a battery, the metal stand being connected with the other. When the current is established along the wire, it will vibrate rapidly in a longitudinal direction, and the coils approach each other, by which connection is broken; the weight of the wire causes it to descend, and, touching the mercury, the current is again restored.

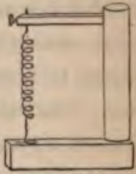


Fig. 182.

If wires conducting electricity are placed over the poles of a magnet, the wires being at the same time free to move, the tangential force of the magnet and of the electricity transversing the wires sets them in motion, and they rotate about the poles. In a similar manner a moveable magnet may be made to rotate around wires carrying an electrical current. A large variety of apparatus is constructed for producing these rotations, and in many of them the reciprocal actions of galvanic currents upon each other, of these currents on magnets, and of magnets on these currents, are very ingeniously shown.

The influence of terrestrial magnetism on weak electric currents is proved by a very simple piece of apparatus. A copper wire (Fig. 183) bent into a circular shape, with its two ends passed through a cork, and a small piece of zinc, z, and another of copper, c, attached to them, is placed upon a vessel of water. The small amount of chemical action set up on the zinc plate developes an electrical current, which traverses the wire towards the copper plate, which immediately takes a polar direction, and if the wire is placed E. and W., it will return to its position N. and S.

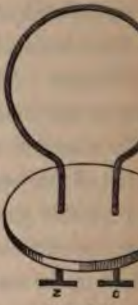


Fig. 183.

Ampère has propounded a theory of magnetism from a consideration of the phenomena which have been described, and which, indeed, explains a greater number of facts than any other. According to the hypothesis of Ampère, every molecule of a magnet is supposed as surrounded with an atmosphere of electricity, which is constantly circulating around it, the difference between a magnet and a mere bar of iron being, that the electricity which exists equally in the iron, is at rest, whereas in the magnet it is in motion. The production of a magnet, according to this view, is best illustrated by taking two cylinders and tracing around them imaginary lines, running contrary ways, as showing the direction of the electrical current:—the magnetic force being exerted at right angles to these lines, we have, if we place them before us, two opposite poles towards us; the current running in one direction producing a north pole, that passing along the opposite line giving rise to a south pole.

Few, among the numerous discoveries of Faraday, are of more scientific importance than that of *electro-dynamic induction.* The facts of this discovery may be briefly stated. If, when an electric current is traversing a wire, a second wire is held parallel to it, a current is excited in the second wire, in an opposite direction to the primary current. This current is but instantaneous,—it shows itself when the primary current is, in any way, interrupted; every time contact is made or broken, these secondary currents re-appear. Whenever a magnet is moved in the neighbourhood of a conducting wire, these currents are also induced.

These effects may be easily exhibited. Coil around a wooden cylinder ten or twelve feet of copper wire, covered with cotton or silk, leaving its two ends projecting. Over this wind another and longer piece of covered wire,—say fifty feet,—and connect this with a galvanometer. A current is made to traverse the inner coil of wire, by connecting it with a battery, and every time contact is made or broken, a deflection by the induced current takes place in the needles of the instrument.

If a bundle of wire is coiled as in Fig. 181, and the two ends are connected with a galvanometer, that instrument will indicate the disturbance due to an electric current, every time a magnetic bar is passed into the coil, or withdrawn from it.

Without involving the question by any further statement of these curious phenomena, these two illustrations of the elementary experiments will enable any reflecting mind to satisfy itself of the identity of magnetism with ordinary electricity. It has now been shown that a copper wire, traversed by an electric current, or electrically excited, exerts, *laterally*, a magnetic force. It has also been explained that two copper wires, in this electrical state, act as if they were magnets towards each other; and while a current traverses such a wire twisted around an iron bar, that bar becomes a magnet; and, again, a magnet moved near a coil of copper wire, produces in it an electrical current, by induction.

The knowledge of these facts has led to the construction of machines by which electricity is at once obtained from permanent magnets. The magneto-electrical machine is shown in Fig. 184. A compound

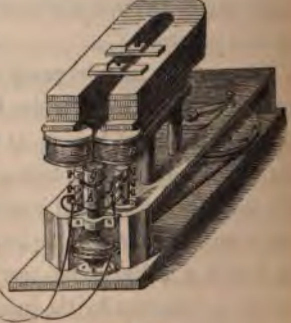


Fig. 184.

horse-shoe magnet, consisting of several permanently magnetic steel bars, is bolted to a mahogany stand, arranged in such a manner, that two coils, A, B, of fine copper wire, clothed with silk, with cores of soft iron, may be fixed on a bar of iron, which is mounted on an axis, and connected by a band with a multiplying wheel, shown in the hinder part of the woodcut; the ends of the wire in these coils are kept pressed, by means of springs, against a good conducting metal plate. The iron on which the coils of copper wire are placed acts as the armature of the magnet; consequently, when these are at rest and opposite the poles, the iron becomes, by induction, magnetic; when moved from the poles, this ceases; so that, in moving them round in front of the compound magnet, their polarities are constantly changed, and magnetism regularly induced and annihilated. Every time these changes take place, a current of electricity passes through the wire, and, by turning this armature very rapidly, a succession of brilliant sparks are produced. By connecting a small piece of platinum wire in the circuit, it is rapidly rendered white-hot. By conveying connecting wires from the magneto-electric machine into acidulated water, its decomposition is effected; and many chemical compounds may, in like manner, be resolved into their ultimate constituents: machines, indeed, of this kind are used for electro-plating in Birmingham. The effects on the human system are distressing. If two copper discs, connected with the machine, are grasped by the hands, slightly moistened, and the armature is made to revolve rapidly, the muscles are closed so firmly, that the cylinders cannot be dropped, and most intolerable convulsive shocks are sent through the arms and body.

It will readily be perceived, that many different contrivances might be made, by which the revolution of coils of copper wire, upon soft iron cores, could be effected; and some have been devised, in which the use of soft iron has been entirely abandoned. It may, however, be well to state a very simple method by which the spark from a magnet may be obtained. Take a powerful horse-shoe permanent magnet, and place a bar of soft iron upon it, as an armature; wind about this about fifteen or twenty yards of thin copper ribbon, with pieces of dry paper on one side, so that the copper convolutions nowhere touch each other; the two ends are left loose, one is flattened, and the other, which is to be pointed, is made to spring against the flat surface. Things being thus arranged, one end of the bar is lifted from the magnet; a bright spark will be immediately visible, in a dark room, between the two ends of the copper ribbon, and the same again upon replacing the armature on the pole. If the ends of the copper band are connected with a galvanometer, the needle will be deflected every time contact is made or broken.

If a copper disc is so mounted, that it can be made to *revolve rapidly between the poles* of a powerful magnet, and wires adjusted, one to press against the axis, and another against the circumference of the disc, and this arrangement is connected with a galvanometer, the needle will, by its deflection, indicate a considerable amount of electricity, whenever the disc is made to revolve rapidly.

The discovery of magneto-electric induction afforded an explanation of some curious facts, first observed by M. Arago, in 1829. This experimentalist, being desirous of ascertaining if any influence was exerted on a delicately suspended magnetic needle by any bodies not magnetic, brought near it, found, that when metallic substances were used, they brought a vibrating needle very much sooner to rest than when such were not employed. The experiments were of the following character:—A small bar magnet was suspended by a piece of untwisted silk, and surrounded by a ring of copper. The bar, being drawn aside 45 degrees from the meridian, was allowed to vibrate, and the number of vibrations taken between 45° and 10°. The same being determined when the copper ring was removed, it was found that in free space the bar performed 420 oscillations before it reached an arc of 10 degrees; whereas, when surrounded by the copper ring, only 14 oscillations were performed before they were thus far reduced, thereby showing the great influence of the metal. Within a ring of wood the oscillations were reduced from 420 to about 300. (Harris.)

These results leading to further investigation, it was shortly discovered that the influences of the metals on a magnetic needle were sufficiently strong to drag it from a state of rest, if they were made to rotate in its neighbourhood. This is not due to any currents of air, since it has been shown that under glass screens, in the best vacuum of an air-pump, a plate of copper or other metal, set in rapid movement under a magnetic bar, very soon imparted to it the same speed; or if the magnet was made to revolve over a lightly suspended metal disc, the latter soon revolved with the speed of the former.

The induction of electricity in any metallic bodies moved in the neighbourhood of a magnet fully explains these discoveries of Arago and Harris.

Having now described the principal phenomena of magnetism, under the different conditions in which science has enabled us to pursue this subtile agent, it becomes necessary to examine some of the phenomena of natural or *Terrestrial magnetism.*

Any bar of iron or steel in a magnetic condition is directed by some invisible force to point towards the north and south poles of the earth; that is, to a point about 25° to the west of the true north; this deviation being called the *variation of the needle.* A bar of soft iron suspended sufficiently long, will, although it at first points indifferently to any part, gradually become magnetic, under the influence of this unseen agent, and point as in the former case. The compass-needle, pointing with undeviating truth to a certain point on the globe, affords the mariner the means of at all times knowing the direction of his bark amid the vast solitudes of ocean, when he could have no other guide.

If a bar magnet is freely suspended, it not only points to the north and south, but it is inclined towards the earth. This is called the *dip of the needle*, and in this country it amounts to about 70° from the horizontal line.

When a delicately suspended magnet is drawn out of its position, and then set free, it will perform a certain number of oscillations before it again returns to a state of repose. When this observation is made at different places, at various seasons, and at dissimilar hours of the day, it is found that the number of oscillations vary. This depends upon the amount of terrestrial magnetic force acting on the oscillating bar; and thus we measure the *intensity* of the earth's magnetism, and learn, that there is a diurnal and monthly variation, and a variation dependent upon latitude.

In explaining the variation of the needle, it is necessary to remember that there are two lines along the surface of the globe, where the magnetic needle points to the true north. These are, however, exceedingly irregular, showing that the powers on which terrestrial magnetism depends are regulated by causes which science has not yet reached. The *western line of no variation* begins in latitude 60°, to the west of Hudson's Bay, passes in a south direction through the American lakes, the Antilles, and Cape St. Roque, reaching the Atlantic Ocean, and cutting the meridian of Greenwich in about 65° of south latitude. The *eastern line of no variation* begins, on the north, in the White Sea, makes a great semicircle, descending south, till it reaches the latitude of 71°; it then passes along the Sea of Japan, goes westward across China and Hindostan, to Bombay; it then bends to the east, and reaching the north-west shore of Australia, runs south in nearly a direct line to about longitude 130° east of Greenwich. These two lines indicate four *magnetic* poles, or, as Hansteen calls them, *four points of convergence*. By comparing observations which have been made at different times, Hansteen concludes that these poles have a regular motion around the globe, the two northern ones from west to east in an oblique direction, and the two southern ones from east to west. Hansteen calculates their periods of revolution as follows:—

The strongest north pole in 1740 years.
The strongest south pole in 4609 years.
The weakest north pole in 860 years.
The weakest south pole in 1304 years.

This magnetician has pointed out a curious connection between these movements and the precession of the equinoxes. The shortest time in which all the four poles can accomplish a cycle, and return to the same state as at present, coincides exactly with the period in which the precession of the equinoxes will amount to a complete circle, reckoning the precession at a degree in seventy-two years.

The annual variation of the needle at London, for a few years widely separated, may be inferred from the following table:—

Years.	Observers.	Variations.
1576	Norman	11° 15′ 0″ East.
1580	Burroughs	11 17 0 Maximum of E. variation.
1657	No variation.	
1662		
1670	. . .	2 6 0 West.
1700	. . .	9 40 0
1760	. . .	19 30 0
1800	. . .	24 36 0 Maximum of W. variation.
1815	Col. Beaufoy	24 27 18
1820	. . .	24 11 7
1831	. . .	24 0 0

Similar variations have been observed in many of the civilized parts of the globe.

The observations on the monthly variations of the needle prove, that between the months of January and April the magnetic needle recedes from the north pole of the earth, while from April to July the western declination diminishes; and from the summer solstice to the vernal equinox, it increases.

The diurnal variation commences about seven A.M.; the north end then begins to deviate to the west, and it reaches its maximum westerly deviation about two P.M.; it then returns towards its original position.

The dip, or inclination, of the needle.—If a bar of steel is suspended from its centre, and carefully balanced, it will hang horizontally, having no disposition to *dip* from the horizontal line either on one side or other of the centre of suspension. If we now pass a magnet along the bar, so as to impart magnetism to the steel, it will be immediately inclined from the horizon about 70°. Such magnet, suspended at the equator, will remain in its h zontal position; as we advance either northward or sou ward from the equator towards the poles, the needle *di* and this increases, until, arriving at the magnetic pol it hangs vertically. Therefore, near the equator the i clination is nothing; and a line passing round the glob which is marked as the line of no dip, and which is irr gular, crossing the earth's equator at four points, is th magnetic equator. The general inclination of the magn tic to the terrestrial equator is 12°. The nodal point where the two intersect, have been carefully examine and laid down with much precision, from the observatio of Hansteen, Duperrey, and Morlet; and, more recentl much additional information has been obtained by th establishment of magnetic observatories in all parts of th globe, and by the attention which Ross and others hav paid to magnetic observations in their surveying voyages

A few examples of recent determinations of the dip wi show the amount of inclination from the horizontal i various parts of the world.—

Pekin	54° 48′ 9″
Göttingen . . .	68 22 52
Falmouth . . .	68 56 0
Plymouth . . .	69 27 6
Edinburgh . . .	71 37 0
New York . . .	73 14 0
Montreal Island . .	87 45 0
Point Beaufort . .	88 13 0

Like the variation, the dip of the needle undergoes continual change, increasing in some parts of the world, and diminishing in others. The dip in London was measured by Graham in 1720, at 74° 42′; in 1800 by Gilpin, at 70° 35′; and in 1830 by Captain Kater, at 69° 38′; and it is still diminishing. This progressive variation in the dip depends upon the motion of the nodes of the magnetic equator; and it has been shown by Hansteen, that the dip during the summer was fifteen minutes greater than during the winter, and four minutes greater in the forenoon than in the afternoon.

Thus the magnetic needle is mysteriously affected by the sun's course, variations of temperature producing uniform changes in dip and intensity. To a similar cause is, without doubt, due those very remarkable perturbations which are known as *magnetic storms*. These were discovered by the remarkable fact that at all the magnetic observatories of the old or the new world, there was a *simultaneous* disturbance of the magnetic needles. These have, on some occasions, been associated with displays of *aurora borealis*: but as this is not always the case, the cause of these "storms" has to be sought for in some other agency than that which produced the electrical manifestations of the Northern Lights.

For the purpose of carrying out magnetic observations, numerous instruments, possessing the greatest degree of delicacy, are necessary. Among them may be mentioned *Magnetoscopes*, which are merely highly magnetized bars, very delicately suspended by a flexible thread, or mounted upon an agate pivot; *magnetometers,* which are of several kinds, the object of all of them being to measure the force necessary to draw a magnet from a given position; *dipping needles,* and some modifications of the compass-needle of the mariner.

The phenomena of the earth's magnetism have been a most fruitful subject of speculation. Dr. Gilbert supposed the earth to contain within itself a powerful magnet, which acted upon magnetic bodies on the surface, in the same way as two or more magnetized bars of steel are found to act in our experiments. Hansteen imagines the sun to be, to us, the exciting source of magnetism. He says—"The sun may be conceived as possessing one or more magnetic axes, which, by distributing the force, occasion a magnetic difference in the earth, in the moon, and all those planets whose internal structure admit of such a difference. Yet, allowing all this, the main difficulty seems not to be overcome, but merely removed from the eyes to a greater distance; for the question may be still asked, with equal justice, *Whence did the sun acquire its magnetic force*? And if from the sun we have recourse to a central sun, and from that again to a general magnetic direction throughout the universe, having the milky way for its equator, we but lengthen an unrestricted chain, every link of which hangs on the preceding link, no one of them on a point of support."

Sir David Brewster was the first to prove that there were in our northern hemisphere two points of maximum cold; that these poles coincided with the magnetic poles; that the circle of maximum heat, like the magnetic equator, did not coincide with the equinoctial line; that the isothermal lines (lines of equal temperature), and the lines of equal magnetic intensity, had the same general form, surrounding and enclosing the magnetic poles and those of maximum cold.

Magnetism and heat stand in strict relation to each other. The author has found that melted iron did not affect the most delicate compass; but as it cooled below a certain point, its attractive influence was again exerted. By heating a bar magnet, we gradually weaken and eventually destroy its magnetism.

Professor Barlow was the first who reduced to an experimental form the idea that the phenomenon of terrestrial magnetism was of electric origin. He took a hollow globe and surrounded it with copper wire, along which he occasioned an electric current to circulate. When connected with a voltaic battery, the whole surface of the globe was put into a state of transient magnetic induction, and a needle, freely suspended above it, arranged itself in a plane passing from pole to pole through the centre, and took different angles of inclination, according to its situation between the equator and either pole.

Mr. Barlow in England, and Baumgartner of Vienna, have detected in the wires of the electric telegraph, which have an earth connection, electric currents circulating from the east to the west during the hours when the sun is above the horizon. We have already seen that a magnetized bar has a tendency always to place itself at right angles to an electric current. Therefore, supposing our globe to be involved in an electric atmosphere, the lines of its disturbance being parallel, or nearly so, to its equator, any magnetic body would arrange itself across those lines. We have thus a very simple and sufficient explanation of the phenomenon of north and south direction in the compass-needle.

Dr. Seebeck proved that the mere application of heat to a point on a ring composed of two dissimilar elements, developed magnetic effects; and the recent discoveries of Faraday appear to show, that the materials of which the earth is constituted are susceptible of receiving magnetism by induction from an exterior cause. The experiments must be described with some care, as they involve considerations, of the great problem of magnetism, which are not exceeded in importance by any of the discoveries of inductive science.

An apparatus of the following kind was devised by Dr. Faraday. A horizontal lever was suspended by cocoon silk, and at right angles, at the end of one arm, was attached a horizontal cross-bar, on which, at about an inch and a half apart, and equidistant from the horizontal lever, were suspended two glass bubbles. When this differential torsion-balance was adjusted for experiment, one of the glass bubbles was on either side of the iron core of an electro-magnet. These glass bubbles were filled with atmospheric air, or any given gas, in a state of condensation or attenuation, and the results were, when nitrogen and oxygen bubbles were employed, that the oxygen was attracted to and the nitrogen driven from the magnet; thus proving the magnetic character of the life-sustaining portion of our atmosphere, and the neutrality of the other; this was also proved with regard to nitrogen, by the fact, that no difference in density produced any variation in its magnetic character. Oxygen at half an atmosphere was less magnetic than that at one atmosphere, but more magnetic than oxygen of one-third this density, while that at one-third surpassed a vacuum in magnetic character.

These results teach us that our atmosphere is a magnetic medium, and that its magnetic intensity varies with every alteration in its density. Four-fifths of the air is nitrogen, and this, Faraday has shown, is a gas which neither under differences of temperature, nor of expansion, shows any alteration in its power of affecting magnetic force. Oxygen forms the remaining fifth of the atmosphere; this magnetic gas is proved to have its character altered by every variation of temperature. Faraday is hence disposed to refer all the phenomena of magnetic variations to the influences of solar heat on the atmosphere.

Magnetism may be fairly assumed, from all the experimental results which have been obtained,—the most important of which have been described,—as a peculiar form of electricity.

All matter has the power of holding around its atoms, in a state of extreme condensation, this and the other physical forces. Now, the earth is a great reservoir of electricity, and under the influence of the solar radiations it is disturbed; a current circulates from east to west, and all bodies holding this agent in a state of statical equilibrium are moved, the result being the development of the dynamical effects of a disturbed state of the electrical equilibrium.

The *Aurora Borealis* is a very striking manifestation of this electro-magnetic disturbance, taking place at a considerable elevation in the atmosphere. The aurora is usually confined to a region 150 miles above the earth, and Dr. Dalton's theory is as follows:—Immediately above the earth's surface is the region of clouds, then the region of meteors, falling stars, and fire-balls, and beyond this region that of the aurora borealis. The light of the aurora is extremely attenuated, and hence it is inferred that it is produced in an atmosphere as attenuated as the Torricellian vacuum, and it corresponds exactly with the light of an electric spark sent through air which has been rarefied as far as it is possible, by means of a good air-pump. Dalton supposes this region to be filled with fluid magnetic matter, and, adopting the experimental evidence of the existence of iron in the atmosphere, given by Fusinieri, he supposed that the *beams of the aurora borealis were of a ferruginous nature.* We now are enabled to discard this assumption, since oxygen is shown to possess a magnetic character of the same kind as iron, and differing from it only in degree. We know not what chemical changes may take place in the atmosphere at the extreme degree of attenuation of the auroreal regions, where, also, the cold must be exceedingly great. Dalton says, "With regard to the exciting cause of the aurora, I believe it will be found in change of temperature:" this view completely agrees with the experiments of Faraday. Regarding the aurora to be due to a disturbance of a magnetic body by changes of temperature, its peculiar manifestations must be referred to the influences of the mass of the earth. Dalton's expression is in all probability the true one: *The aurora borealis is a magnetic phenomenon, and its beams are governed by the earth's magnetism.*

Light has been stated to have the power of inducing magnetism in steel. Morichini, Carpa, Ridolfi, and Mrs. Somerville, state, that by exposing sewing needles to the violet rays of a prismatic spectrum, or by covering one-half of them with a blue glass, they become magnetic. Much doubt has, however, been thrown upon these results, as they have not been confirmed by other experimenters. It would appear, however, from experiments which the author has made on this subject, that magnetism is induced by the action of the solar rays when the needles are placed in the line of the magnetic meridian, and in the direction of the dip of the needle at the place where the experiment is tried. The result is without doubt due to the disturbance of the molecular arrangement, and it bears a very close resemblance to the magnetism induced by a blow on a bar of steel under the same circumstances.

The important part which Electricity performs in the great phenomena of nature, will, it is hoped, be now fairly understood. The practice, however, of referring every effect, which we cannot clearly trace to its cause, to electricity, is one which cannot be too strongly censured, since it leads to misconception, and stops the progress of inquiry. Electricity, galvanism, and magnetism stand as different forms of the same great power, and to these may be referred many remarkable results which have through all time excited the attention of man; our knowledge of them will be extended, but the probability is, that with the extension of our knowledge we shall discover physical agencies which stand far superior to any with which we are now acquainted.

CHAPTER VII.

HEAT, OR CALORIC.

In common language two meanings are given to the term *heat*, one signifying the sensation produced on touching any hot body, and the other the cause producing that sensation. In the language of science, to avoid as far as possible the inconvenience of employing the same word in two senses, it has been usual to adopt the term *Caloric* to signify the cause, *Heat* being the effect. This distinction has not been always adopted by scientific writers, and it has been particularly rejected by those who will not admit the materiality of any of the physical forces; but there appear to be so many advantages connected with it, that it will, in the present chapter, be strictly adhered to.

The first great source of this important principle, or force, is undoubtedly the sun, and we find, upon examination of the solar beam, that the heat radiations do not obey precisely the same laws as those which we detect regulating the luminous rays. Sir William Herschel and Sir Henry Englefield were the first to examine the temperature of the solar rays. This examination was effected by placing very delicate thermometers across the prismatic rays: they obtained the following results:—

Quite out of visible light, below the Red ray,	the thermometer rose	18	degrees.
In the Red ray,	,,	15½	,,
In the Yellow ray,	,,	6	,,
In the Green ray,	,,	4	,,
In the Blue ray,	,,	1	,,

Sir John Herschel, by more recent researches, has confirmed these results, and also proved an extension of the calorific spectrum beyond the limits of the luminous rays, far greater than had hitherto been suspected. His method of examination is as follows:—A piece of tissue paper is stretched on a frame, and blackened on one side only. It is then placed so that the prismatic image falls on the unblackened side. Being thus carefully adjusted, and a well-defined spectrum obtained, a wash of ether is passed, by means of a wide brush, fully over the paper. The ether, being very volatile, evaporates rapidly, the portion subjected to the greatest heat drying the most speedily, and marking, by spots whiter than the other parts of the paper, the extension and defined limits of the calorific rays. This is shown in Fig. 2 of the frontispiece, which is adjusted, in its relation to the luminous spectrum, in such a manner as to convey a correct idea of the superior extent of the calorific radiations. The spot which corresponds with the crimson ray is the first which becomes visible from drying, thus marking the point of greatest heat; the larger spot dries more slowly, but it is always exceedingly well-defined; and the two lower and smaller spots are only made visible by a second copious application of ether. The appendage from the first heat-spot, which extends through the luminous rays up to the blue, marks in a very pleasing manner the gradual diminution of thermic influence, and fully confirms Sir William Herschel's thermometric examination.

The points for consideration here are, the difference between the calorific and the luminous rays, as it regards refrangibility;—we detect heat-rays scarcely at all bent by the interposition of the prism;—the want of coincidence between the light-giving and the heat-producing rays, and the very rapid diffusion and diminution of the calorific rays, as soon as they become blended with the luminous bands. Out of this arises the question—Are light and heat identical? are they modified forms of the same force? It has been shown by Drs. Robinson and Draper, that all bodies become luminous at the same temperature. Every substance in nature, whether organic or inorganic, begins to emit light at about 1000° Fahrenheit, from which it has been inferred that a certain degree of disturbance produces heat, which, being increased, gives rise to luminous vibrations.

Heat and light may, however, be separated from each other. Melloni has determined that although thin slices of obsidian and black mica obstruct nearly all the luminous rays, yet these bodies admit the free and full permeation of the calorific rays; whereas, a peculiar green glass, washed over on one side with a solution of alum, although perfectly transparent to light, is nearly opake for heat, most of the solar calorific radiations being cut off when such a glass is interposed as a screen. By coloured solutions we are enabled to produce similar results, and thus secure the isolation of heat and light.

The other sources of heat, which may be called by distinction the terrestrial ones, are summed up under the following heads.—

Mechanical force, whether applied as friction or percussion. A piece of metal rubbed rapidly on any other body, soon becomes too hot to be held. Two pieces of dry wood, kept for a few minutes in a state of brisk attrition, will give rise to such a development of caloric as will occasion their ignition. The lucifer match is ignited by the heat produced by the friction of the chemical compound against a piece of sand-paper. Count Rumford found that the friction produced in boring a brass cannon of seven inches and a half diameter, the borers pressing with the force of 10,000, and making thirty-two revolutions a minute, developed, in two hours and a half, sufficient caloric to raise eighteen pounds of water up to the boiling point.

Percussion caps, and detonating balls, are familiar examples of the effects of sudden blows in liberating caloric. The blacksmith will hammer a piece of iron until it becomes red-hot. In striking coins, we have a very instructive example of the fact, that as bodies are diminished in bulk they evolve heat: it is found in coining, that with the first blow of the coining-press, by which the molecules of the metal are squeezed closer together, the largest amount of heat is manifested; the rate of increase becoming less at every blow.

Chemical action is a very active source of heat. Under this head all the phenomena of combustion must be included; the burning body—coal in the fire, or tallow in the candle—combining with oxygen in the process. When we mix any two bodies which condense into a smaller volume when combined, than they occupied in a separate state, heat is manifested, often in a very remarkable manner. Examples of this action are mixtures of oil of vitriol and water,—of nitric acid and alcohol;—and, among the metals, as in the combinations of lead and tin, or bismuth and tin, and even in copper and zinc, we have the curious instances that, after these compounds have cooled to a certain point, they suddenly become again too hot to be handled: this development of caloric being due, it would appear, to some rearrangement of the particles.

Electrical action. Whenever the electric current progresses through a conducting body which offers much resistance to its passage, heat is developed. The incandescence of platinum wire, and the arc of luminous and calorific intensity (the electric light) between the charcoal points which form the termination of a galvanic series, are illustrations of the heating powers of electricity. As a practical application, the process of firing gunpowder under water, or of exploding a mine, may be adduced.

Vital action. This source of heat appears to be a compound influence of mechanical action, as in muscular movement,—of chemical power, as in the processes of digestion and respiration,—and of electrical influence, as in the operations of the nerves, and of the brain, regarded as the nervous centre.

Heat is a universal force, moving according to laws which are peculiarly its own, although in some respects they approach nearly to those which regulate the motions of light. Calorific radiations are capable of being reflected, and undergo polarization under the same circumstances as do the luminous rays.

We speak of free caloric, and mean thereby the circumstance of heat becoming *sensible*, as when diffusing itself, in its tendency towards an equilibrium, through all surrounding bodies. When an equilibrium is restored, and all neighbouring bodies are at an equal temperature, this agency is said to be *latent*, or in a state of repose. The doctrine of *latent*, or hidden heat, has been disputed by those philosophers who are disposed to regard heat as a mere property of matter, its sensible effects being due to motion. When, however, we consider the evidence which experimental science affords us, of phenomena during which caloric appears to be squeezed out of solid or gaseous matter as the molecules are brought closer together, the hypothesis of latent heat receives the strongest support.

We are absolutely ignorant of the nature of the principle of heat: we know that certain effects result, and we attempt to explain these by theory. Our senses make us familiar with two conditions, *heat* and *cold*; these are precisely the same forms of expression in relation to caloric, as positive and negative are to electricity. We feel warmth when caloric is added to our bodies, we are sensible of cold when heat is abstracted. This duality of action extends through all nature; and the constant effort made by the physical agencies to maintain a perfect equilibrium is, in all probability, the great exciting cause of the phenomena with which observation has made us familiar.

Caloric, or the principle of heat, is directly antagonistic to the force of cohesion, by which particles of matter are chained to each other.

Whatever may be the state of a body, it suffers expansion if it is subjected to a higher temperature than itself. Gases expand by heat, far more than solid or fluid bodies do. If a flaccid bladder, tied securely at the mouth, is held near the fire, it will, from the expansion of the air within it, become in a short time full and tense;

and if the heat be continued, the membrane will burst, from the further expansion of the air within. If we fit into a Florence oil-flask a long glass tube, and then place the end of the tube in a vessel of water, we have a rough, but easy means, by which the expansion of the air within it may be measured. If the warm hand is applied to the flask, the air, expanding, will escape in bubbles through the water; on removing the hand, the flask returns to the normal temperature, and the air, resuming its former condition, is not sufficient to fill the flask and tube; water rises in the tube to supply its place, the quantity of liquid marking the degree of expansion which had taken place with a certain increment of heat. Upon this principle, a very delicate instrument, the *air thermometer*, has been constructed.

Fluids expand in a similar manner. If we place water, mercury, or oil, in the flask employed in the last experiment, so that a little of the fluid rises in the tube, and apply any heat to the flask, the fluid, by expansion, will gradually rise in the tube; upon which, if graduated, we can mark the degree of expansion for any addition of caloric. The expansion of the volume, with an increase of temperature from 32° Fahr. to 212°, may be thus expressed:—

Mercury:	1000 parts	become about	1018
Water	,,	,,	1045
Alcohol	,,	,,	1100
Oil	,,	,,	1095

Alcohol expands much more than water, and water more than fluid mercury.

If we take any solid body, and measure its length, breadth, and thickness at a fixed temperature, we shall find, upon applying heat to it, that it will have increased in every direction. If an iron rod is taken, which exactly passes into a gauge eighteen inches, or any other measure, in length, and to which we fit easily an iron ring; upon making the bar hot it will be too long to fall into the gauge, and have increased so much in thickness, that it will not pass through the ring. The following are a few examples of the rates of expansion in solid bodies;—the elongation, when heated from 32° to 212°, being

Copper . . .	$\frac{1}{581}$	of its length.
Iron . . .	$\frac{1}{819}$	,,
Lead . . .	$\frac{1}{351}$	,,
Tin . . .	$\frac{1}{462}$	,,
Silver . . .	$\frac{1}{524}$	,,
Gold . . .	$\frac{1}{602}$	,,
Platinum . .	$\frac{1}{1167}$	,,

These numbers are to be regarded as approximations only, and, in repeating experiments, it must not be forgotten that every sample of metal produced, varies in some physical or chemical property, and hence exhibits some difference in its rate of expansion.

Taking advantage of the knowledge obtained by the investigations which have been very carefully made into the laws of expansion in bars of metals, we have been enabled to give a constancy to the lengths of the pendulum; every variation in the length of which produces a corresponding variation in its rate of oscillation. *Compensation pendulums*, as they are called, are variously made; the most common form being the *gridiron pendulum*. In this, the main rod is of iron, and the inner ones of zinc or brass. As the expansion of zinc exceeds that of iron, the bars are made unequal; and such a relation is established between them, that the elevation of one exactly counterbalances the depression of the other. The *mercurial compensation pendulum* is another form, in which the same kind of compensation is effected by means of fluid mercury and iron. The *compensation balance*, in chronometers, depends on the same principle; two different metals being soldered together, so as to render the movements uniform.

Upon a knowledge of the laws of expansion under calorific influence, is founded the construction of *thermometers*. They ordinarily consist of a glass tube of small bore, with a bulb at the bottom. These are filled with mercury or alcohol, at a temperature sufficient to ensure the absence of air; the end of the tube is closed, and the whole cooled to the *freezing point*, or that point above which ice melts, and below which water freezes;—this is marked 32°; if now it is plunged into a mixture of ice and salt, a further contraction of the fluid takes place, and that point at which it rests under these conditions is the zero, 0°, of Fahrenheit's scale, usually employed in this country. If the instrument is now placed in water, which is made to boil, the mercury ascends in the tube, and between the point which indicates the temperature of boiling water under the ordinary pressure of the atmosphere, and the zero, 212 degrees are marked.

Réaumur, whose thermometer is much used on the Continent, divides his scale into 80 degrees; his fixed points being melting ice and boiling water. The thermometer of Celsius, of Sweden, usually known as the *centigrade*, has the same space divided into 100 degrees. A degree of Fahrenheit's scale is equal to $\frac{4}{9}$ of one of Réaumur's, and to $\frac{5}{9}$ of a centigrade degree: therefore, to convert a degree of Fahrenheit into its equivalent on Réaumur's scale, the degrees above or below 32° must be multiplied by 4 and divided by 9; and the equivalent on the centigrade scale is obtained by multiplying by 5 and dividing by 9. If, on the contrary, these are to be converted into Fahrenheit degrees, we must multiply the degree on either scale by 9, and divide by 4 or 5, as the case may be.

For convenience of observation on daily variation of temperature, thermometers are made self-registering; the arrangement shown in Fig. 185 (Rutherford's thermometer) being that which is usually adopted. This consists of two thermometers placed horizontally, one being a mercurial and the other a spirit thermometer. In

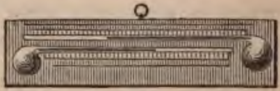


Fig. 185.

the tube of the former lies a steel pin, which is pushed forward as the mercury expands, and is left at the highest point obtained when the metal recedes; the latter has a very fine piece of enamel, or dark glass, somewhat thickened at its extremities, placed in the spirit, as shown in the next figure. As the spirit recedes this is carried back, owing to the adhesion of the spirit to it, and it is left to mark the lowest point to which the spirit has fallen or contracted; as when the spirit expands it cannot be carried forward, owing to the very slight inclination which is given to the tube. These are called *maximum* and *minimum*, and sometimes day and night, thermometers. To adjust them, the steel pin is drawn back with a small magnet moved along near the glass, and by slightly depressing the end of the instrument, the enamel falls to the end of the spirit. The following arrangement, known as Six's thermometer, is often employed (Fig. 186). The tube, fixed to its scale A B, is bent twice; the bulb is in the form of a long cylinder, which is filled with spirits of wine, and in contact with a portion of mercury, occupying the lower part of the tube; and this is succeeded by a second portion of spirit. The mercury carries on each of its surfaces an index, which is retained in its remotest situation by means of a weak spring. By the expansion of the spirit, the mercury is moved, and in

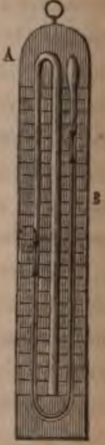


Fig. 186.

one or the other arm are thus marked, by the steel index, the extremes of heat and cold.

Instruments called Pyrometers are used to measure very high temperatures. Wedgwood's consists of a cylindrical piece of porcelain clay, which *contracts* with the increase of heat, and thus marks the degree: the zero of Wedgwood's scale is 1077·5° of Fahr., and each degree equal to 130° of Fahrenheit's. Pyrometers of modern construction act usually in consequence of the expansion of that infusible metal, platinum. In Daniell's pyrometer the change of temperature is shown by the excess of the expansion of an iron bar over the expansion of a black-lead case, in which it is enclosed. The iron rod is shorter than the black-leadware case, and a plug of earthenware, which fits tight in the case, abuts against the iron rod inside. By the expansion of the iron the earthenware plug is pushed out, and it is held so tight in the case, that it cannot go back again when the apparatus cools; the protrusion of the earthenware plug is, therefore, a permanent index of the greatest amount of expansion that had been produced whilst the instrument was exposed to heat. This expansion being very small, the earthenware plug is made to press against a lever, which moves an index over a graduated scale, and thus measures most accurately every degree of expansion.

It has been shown by Dulong and Petit, that although the expansion of fluid bodies up to 212° observes a very regular increase with the proportional increase of temperature, above that point it increases as compared with the expansion of air. This may be explained on the supposition, that, having weakened cohesive force to a certain degree, the particles are more freely separated from each other by the addition of caloric.

Common experience teaches us that bodies conduct caloric, or become heated, at very different rates. If we place a bar of copper and a rod of glass in the fire, with their ends projecting, one will become too hot to be held in the hand long before the other is warm to the touch. If a series of different metal bars are taken and some wax fixed on one end of each, the other end being placed equally in the source of heat, the wax will be found to melt off some long before it is softened upon others. According to Despretz, the rate of conducting power in the following bodies, may be expressed by the numbers attached to each.

Gold	10,000
Silver	9730
Copper	8980
Platinum	3810
Iron	3743
Zinc	3630
Tin	3039
Lead	1796
Marble	263
Porcelain	122
Clay	114

Stones of a dense character stand next to the metals as conductors of heat; then bricks, ordinary earthenware, and glass, which is so bad a conductor that it may be melted an inch from the fingers without any inconvenient heat being experienced. Woods and organic matter, such as bones, are bad conductors; charcoal, however, ranking still lower in conducting power:—if the hand is filled with powdered charcoal, a red-hot iron ball may be held for a long time with impunity. Silk, cotton, and wool are worse conductors than any of the substances named; and the finer the fibres, the less their conducting powers. The warmth preserved by our clothing depends upon the bad conducting material of which it is constructed; the heat which is developed in the processes of vital action being preserved around the body.

In the conduction of caloric through a solid it would appear that each particle communicates to its contiguous particles a portion of that which it receives; and this goes on, in the solid mass, until the whole is of the same temperature; or a change of condition takes place, and fusion results. The communication of heat through fluids is of a different character: the portion warmed becomes specifically lighter than the superincumbent mass, and it rises through it, the colder portion sinking to supply its place, as shown in Fig. 187. If, instead of applying the heat to the bottom of the vessel containing the fluid, it is applied at the top, it will be found that it conducts

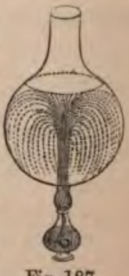


Fig. 187.

caloric downwards but very slowly. If ether is poured on the surface of water, and set on fire, the heat will not affect a thermometer placed at but a short distance below the surface.

Gaseous bodies are still worse conductors than liquid ones: hence they are employed to confine heat, as in the case of double windows; the air between them being the best possible contrivance to prevent the escape of warmth from the apartment. By this property the temperature of the earth is maintained in a more equable condition than it would be if the atmosphere was a good conducting medium.

Count Rumford instituted a series of very complete experiments on the conducting power of bodies used for articles of dress, or the coverings of animals. Suspending a thermometer in a glass tube, surrounding it with the substance to be examined, and plunging it first into boiling water, and then into melting ice, he ascertained the time in seconds which elapsed while the thermometer sank from 190° to 54½°. The following were the results obtained:—

With Air it required		576	seconds.
With 16 grains of Sewing Silk it required		817	,,
With 16 grains of Lint	,,	1032	,,
With 16 grains of Cotton	,,	1046	,,
With 16 grains of Wool	,,	1118	,,
With 16 grains of Raw Silk	,,	1284	,,
With 16 grains of Beaver's fur	,,	1296	,,
With 16 grains of Eider down	,,	1305	,,
With 16 grains of Hare's fur	,,	1315	,,

Practical experience has led to precisely similar results to those obtained by the philosopher, in the employment of these materials for clothing, under different temperatures. There is in nature a beautiful provision, by which the clothing of many animals is changed, when their conditions, as regards temperature, are altered: in the Arctic regions, and during the severe cold of winter, wool replaces hair, and down takes the place of feathers.

Specific Heat.—If we take any number of dissimilar bodies, we shall find, that to raise their temperature from a given point to one higher, they will exhibit different *capacities* for heat. To raise them from 32° to 100° they will require a larger or smaller amount of caloric to be combined with them; similar bodies always requiring an equal quantity of heat to produce a given elevation of temperature above a fixed point.

A simple experiment or two will easily determine these laws. Place upon a hot plate, side by side, two vessels containing equal weights of water and mercury, at a uniform temperature: if after a period we examine the temperature of each, we shall find that the mercury will be much hotter than the water; the capacity of the one for caloric being greater than the other.

When a pound of ice at 32° is mixed with a pound of water at 172°, 140° are absorbed in converting the ice into water, and the temperature of the whole is still 32° Fahr. When, however, a pound of water is frozen into ice, it parts with as much heat as would raise the temperature of a pound of water 140°. Dr. Crawford states the capacity of ice for caloric to be nine-tenths as great as that of water.

The following methods have been adopted for determining the *specific heat* of bodies. They have been mixed together in equal weights, at known temperatures, and their mutual capacities for heat ascertained by the decrease in the temperature of the hotter body, and by its increase in the colder.

If water at 32° Fahr. is mixed with mercury at 66°, the resulting common temperature will be 33°: the water will have gained one degree of heat, while the mercury will have lost 33°. Thus it is proved that the water has a capacity for caloric, which exceeds that of mercury thirty-three times.

Another method is to observe the quantity of ice which the body under investigation is capable of thawing; it having been ascertained, by careful experiment, that 136° of heat are necessary to melt a pound of ice. The rate of cooling is also a means by which the specific heat of a body may be ascertained: the more slowly a body cools, the greater must be its capacity for heat.

Dulong and Petit have shown that the specific heat of all bodies stands in a simple relation to their atomic weights: in nearly all simple substances it is inversely as the atomic weight, the atoms of all such having an equal capacity. The doctrine and laws of specific heat must, however, be studied in the works of their ablest investigators, the aim and extent of the present treatise not allowing of any more extended view.

It will now be understood that every body contains a certain amount of caloric, in a *latent* or non-sensible state, which may be regarded as in physical combination in some definite proportion. To this latent heat is due the condition of the body. In a *solid*, the caloric is not sufficient to place the particles of matter so far from each other, that they are free to move; but in the *fluid* this is the case; and in *gases* the ultimate particles are still further separated by this power. Solids, therefore, contain less latent caloric than liquids, and these less than gases.

Fusion, or *melting*, is the change of a solid into a liquid form, by the addition of caloric to the body: those particles which were held rigidly together by cohesive force, are so far separated, that they are free to move; they float as it were in the principle of heat. In the arts and manufactures, it is of the utmost importance to know with great precision the melting points of various metals. The following table gives the melting points of a few substances:—

Platinum . .	3082° Fahr.	Bismuth . .	480° Fahr.
Iron, wrought	2912	Tin	433
Iron, cast . .	1922	Sulphur . .	226
Gold . . .	2192	Phosphorus .	98
Copper . .	1900	Yellow wax .	110
Silver . . .	1832	Tallow . . .	104
Zinc . . .	700	Ice	32
Lead . . .	590		

Many of the metallic alloys liquefy at a much lower temperature than the metals which enter into their composition. The so-called *fusible metal* is a remarkable example of this. Its composition is as follows :—

Bismuth	248 grains.
Lead	155
Tin	90
Mercury	13

This alloy melts at the temperature of 162° Fahr.; consequently, if put into boiling water, or even water cooled below this point, as in a cup of tea, it runs down like wax. Spoons are sometimes made of this composition, and being used in the way indicated, they very suddenly disappear in the hands of the astonished individual who is ignorant of the experiment.

While a body is fusing, no elevation of its temperature takes place: the increased heat is consumed in producing liquefaction; its capacity for heat is uniformly increased, and a large quantity of caloric is rendered latent. If we cool snow to 20° Fahr., and, having bedded a thermometer in the mass, we bring both into a warm room, the thermometer will immediately begin to rise, and will continue to ascend until it reaches 32°, when it will become stationary, and remain so until all the snow is liquefied; the free caloric of the surrounding air being rendered latent in the water during the process of liquefaction.

Water has the greatest capacity for heat of any body, and, consequently, it is a very important agent in equalizing the temperature of our planet. Owing to the warmth of ocean currents, the variations of climates on sea-coasts are less than those which occur in the centre of continents, the water absorbing the free caloric when the temperature rises, and parting with heat when it falls.

It is found that the temperature of the ocean near the equator varies throughout the year but very slightly, fluctuating but one or two degrees above or below 80°. This warm water circulates towards the polar extremities of the globe, and, by parting with its free caloric, renders those climates temperate, which would otherwise have been scarcely habitable through the excessive cold. A remarkable example of this occurs with the Gulf Stream, which sets from the Gulf of Mexico towards our own shores. The water warmed within the tropics, comes charged with caloric, which it diffuses in our own atmosphere. Along the southern portion of the Norwegian coasts the grain plants cannot be cultivated in consequence of the coldness of the climate, but along the shores of the more northern region of that country they grow with tolerable facility. This arises from the circumstance that a portion of the great Gulf Stream escapes to the north of Ireland, and, passing the islands of Scotland, sets full on the Norwegian shore, where it parts with the last portion of that heat which is in excess above the atmospheric temperature, and thus renders the climate milder than further south.

When fluids are changed into vapours, a conversion of sensible into latent heat, such as we have described, occurs. If we boil water in an open vessel, a considerable portion of vapour or steam is given out, but the temperature never rises above 212°, all the heat which is derived from the fire being rendered latent in the steam. The steam, if condensed, will part with its latent heat to water as sensible heat, and we can thus measure it.

This is very satisfactorily shown in the common *still*, a vessel employed for distilling waters or spirits. Fig. 188, *a*, is a furnace, in which is fixed a copper, to contain the fluid. Heat being applied, the steam rises into the *head*, *b*, and passes thence through the *worm*, *d*, which is placed in a vessel of water, the *refrigerator*; being condensed in its passage, and passing out by the external pipe. In the process, the heat which is imparted to the water to convert it into steam, in which it is latent, is communicated to the liquid in the refrigeratory, and its increasing temperature is, approximately, a measurer of the quantity of caloric which has undergone the change from sensible to latent heat, and back again to sensible.

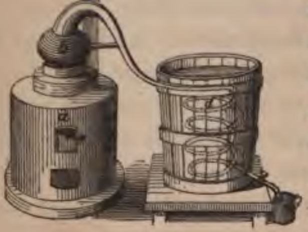


Fig. 188.

The annexed drawing, Fig. 189, is but a more delicate arrangement for determining the same question. *a* is a copper vessel containing water, having a stop-cock *b*, through which the water is poured in, or steam allowed to escape; *c* is a delicate thermometer for ascertaining the temperature of the enclosed water and steam. The steam escapes by the stop-cock *d*, through the pipe *e*; it flows into the water in the vessel *g*, and the thermometer *h* marks the rise of temperature; heat is communicated by the lamp *f*. The whole process is thus under complete control, and very accurate results may be obtained.

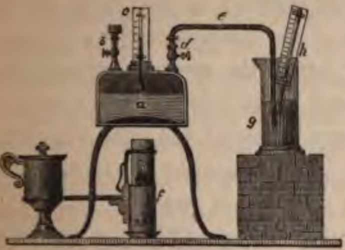


Fig. 189.

The application of steam as a motive power, is one of the most important ministrations of science to the useful purposes of civilization. This depends entirely upon the *elastic force of steam* when heated under pressure, of which an illustration is given in Fig. 190. *a* is a stout copper vessel of a globular form, fixed on a stand *d*; it contains a little mercury; and a tube *b*, which is carefully graduated, goes down into that metal, upon which is placed some water. This is heated by the

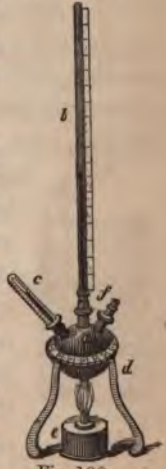


Fig. 190.

lamp *e*, the stop-cock *f* being left open until it boils; it is then closed, and steam being still generated, it presses upon the mercury, which is forced up into the graduated tube *b*. The pressure of the atmosphere being overcome by the steam at 212°, before the mercury begins to rise, if the mercury is forced up to thirty inches, a pressure equal to two atmospheres is exerted, and so on with every increase of pressure. The thermometer *c* is to determine the temperature under variations of pressure.

Water boils at the level of the sea at 212°; as we ascend to a greater elevation, the boiling point of water becomes lowered; thus the boiling of water is sometimes employed as a method by which the heights of mountains may be measured. That water boils at a lower temperature than 212° when pressure is removed, is susceptible of very easy proof. Boil over a lamp, in a glass flask *a*, Fig. 191, some water, and cork the vessel: the pressure of the steam becomes so great as suddenly to check the ebullition. We may allow the flask to cool several degrees, and if we then plunge it into a vessel of cold water, *b*, the water will immediately begin to boil again; the steam is condensed, the pressure is relieved, and the ebullition is again set up: this may be repeated many times with the same result. At the bottom of mines, water will not boil until a temperature higher than 212° is obtained; and on the top of Mont Blanc, Saussure

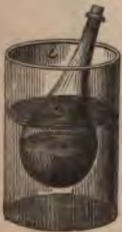


Fig. 191.

found that water boiled at 184°. An ascent of 530 feet causes the boiling point to be lowered one degree.

A pint of water may be evaporated by the combustion of two ounces of coal; and by the caloric which it has received during the change of state of the coal, it has enlarged into 216 gallons of steam, which will exert a mechanical force sufficient to raise a weight of thirty-seven tons a foot high, and by allowing this steam to expand by virtue of its *elasticity*, double this force may be obtained. The knowledge of this is due to the genius of James Watt. In the best steam pumping-engines of Cornwall, a bushel of coal has produced heat sufficient to exert a mechanical force capable of lifting 110,000,000 pounds one foot high. Dr. Lardner has estimated that a bushel of coals thus applied in the Cornish engines, does as much labour as a day's work of fifty strong horses. This is, however, due to the extreme economy of fuel, which is more fully attended to in that county than in any other.

Bodies may, under some conditions, be liquefied without the application of any external heat. The mixing of snow and salt is an example of this, the snow being liquefied at the expense of the free caloric in the salt: the greater the degree of cold generated in the process, the more quickly will liquefaction take place. The absurd and dangerous practice of throwing salt on the footways, when they are covered with snow, may often, from the intensity of the cold thus produced, give rise to the most serious disturbances of health, to even a casual passerby; the practice should, therefore, be decried as much as possible.

Freezing mixtures depend upon these principles: the effects may be illustrated by the following experiments:—

Throw into a glass, around the bulb of a thermometer, a little powdered Glauber's salts (sulphate of soda), and then add some sal ammoniac (muriate of ammonia), also in powder; stir them together, and a great depression of the mercury in the thermometer will immediately ensue.

When salts dissolve in water, they rob the water of some of its caloric, and a thermometer placed in it will sink many degrees.

By mixing diluted sulphuric acid, cooled to the freezing point of water, with snow, we obtain a degree of cold 25° below the zero of Fahrenheit: that is, 55° of cold is obtained.

If fused potash and snow are mixed, both being previously brought to the freezing point, we obtain a depression of 83°, or 51° below zero.

Without the use of snow, very intense degrees of cold can be produced; the following mixture being one of the most effective:—Phosphate of soda, nine parts by weight; nitrate of ammonia, six parts; diluted nitrous acid, four parts. All the materials are to be cooled previously to their being mixed. The temperature falls from 50° to — 21°, or we obtain 71° of coldness.

The greatest cold obtained by Mr. Walker, who paid much attention to this subject, was 100° below the zero of Fahrenheit.

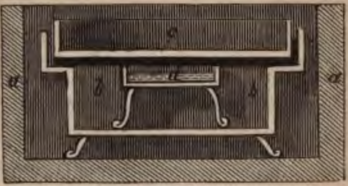


Fig. 192.

The arrangement represented in Fig. 192 is that usually employed for freezing mercury, and other bodies. It consists of a tin box, having double sides, *a*, *a*, which is filled with air. In this is placed another vessel, *b b*, which contains a freezing mixture, *b b*: the space between it and the outer vessel may be filled with another freezing mixture, if we desire to produce very intense cold; in the frigorific compound *b b*, a small vessel, containing the mercury *d*, is fixed, and a cover *c*, into which a similar mixture can be placed, is put on: all is left quiet for a short space of time, and the cold compound robs the mercury of the heat of liquefaction, and it becomes solid.

Water, if kept perfectly still, may be cooled many degrees below its point of congelation, without freezing; but the moment it is disturbed in any way, it becomes solid. In freezing, there are some peculiar conditions connected with water, which must not be overlooked. This fluid is at its maximum density at 40° of Fahrenheit; in cooling further, an apparent expansion takes place, and water colder than this floats on the warmer fluid. This may, I think, be explained, without that mysterious alteration of a fixed law, which is sometimes had recourse to, as a means of explanation. Water, in cooling below this point, commences an arrangement of its particles, preparatory to their passing into the solid form, different from that which previously obtained; the grouping of the molecules partakes of an angular rather than of a spherical character, and hence in one direction they occupy more space; and solid water at 32° floats on the liquid water above that point, and actually parts with some of its caloric to warm the fluid beneath the ice.

That a new arrangement of the molecules takes place, is proved by the fact that water in freezing rejects everything which may have been combined with it. If ice is taken from the still waters of a pond, it will be found full of air-bubbles; but if it is taken from the sides of a rapid river, or of a cataract, it will be perfectly free from all air. Mix with water a solution of indigo, which will impart to it the most intense blue colour; add to it the strongest and most corrosive acid; dissolve in it the most acrid poison; or disseminate through it any spirituous compound; and freeze the mixture by means of one of the frigorific mixtures already named, gently moving the water with a feather during the process. The ice which forms around the sides of the vessel containing it, will be colourless, tasteless, and harmless; it is absolutely pure water, and nothing else. The colouring matter, the acid, the poison, or whatever it may be, has been forced out of the water; and it will be found in a concentrated form in the centre of the solid mass. Russian noblemen sometimes freeze their wines, for the purpose of obtaining the concentrated nectar which they thus form in the centre of the bottle.

Water thus deprived of air and all other matters, appears to obey some different law in relation to heat. If a piece of ice, formed as we have now described, is put into a flask covered with a slight film of oil, to exclude, and thus prevent the absorption of, air, during liquefaction, and then submitted to the heat of a spirit-lamp, the temperature may be raised to 280° without ebullition taking place; but on reaching that point it explodes with very considerable violence. To the operation of this peculiar cause, may, in all probability, be referred many of the steam-boiler explosions which occur. The following are the points of congelation of a few dissimilar substances:—

Fresh Water freezes at	32°
Sea Water	26
Sulphuric Acid	1
Oil of Turpentine	14
Olive Oil	36
Brandy	— 7
Mercury	—39
Liquid Ammonia	—45
Sulphuric Ether	—46

The most intense cold has been produced by the use of solid carbonic acid and ether. The carbonic acid is rendered solid, by pressure in the first instance, and then by its own evaporation, on its being allowed to escape into the air. By the employment of this bath of Thilorier, which sinks to 166° below zero, the following bodies have been reduced to the solid state:—

Cyanogen at	— 30°
Chlorine and Oxygen	— 75
Gaseous Ammonia	—103
Protoxide of Nitrogen	—150

At the same time, however, some amount of mechanical pressure is necessary to effect the solidification of these substances.

The greatest natural cold observed, was probably that measured by Hansteen, in lat. 55° N., which, according to his statement, must have been more than 90° below the zero of Fahrenheit. During the year, January is on the average the coldest month, and July the hottest. In the northern temperate zone, the mean annual temperature generally occurs about the middle of April and the middle of October. The laws of the distribution of temperature on the surface of the earth, may be thus expressed:—

Heat diminishes from the equator towards the poles.

The rate of its diminution is materially modified by the action of aerial and of oceanic currents; also by the conditions of continents, and, relatively, the extent of land and water.

If the whole earth's surface were covered by water, or if, with the absence of water, it presented a uniform surface, the rate at which heat would diminish would be uniformly regulated by latitude.

The distribution of the humidity of the atmosphere is another modifying cause. This depends upon the relative quantities of land and sea. From the latter, evaporation is nearly always taking place; and condensation, in the form of rain, mists, and dew, is as constantly occurring over the land. The amount of moisture in the air is detected by instruments known as *hygrometers*; the woodcut (Fig. 193) representing *Saussure's hair hygrometer.* A human hair, A, being freed from all grease, is made fast to a hook, and passed over a pulley fixed in a frame, and attached to a spring, B; the pulley carrying the index C. As the hair lengthens or shortens, it moves the index; and as it is a very *hygroscopic* body, it absorbs or parts with moisture very readily. There are many substances which alter in length with the variations of atmospheric dryness; but the most perfect instruments for this examination are of the class of those already described at page 163.

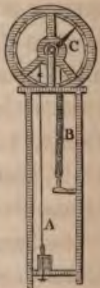


Fig. 193.

Some chemical compounds have the property, in a remarkable degree, of absorbing moisture from the atmosphere, and these are often used for the purpose of drying the air in an experiment; sulphuric acid and chloride of calcium being among the most hygroscopic substances.

The science of climatology particularly embraces the phenomena concerned in the distribution of heat, and the several causes (many of them already alluded to) which determine the temperature of a country. Humboldt first marked out, across the globe, certain lines of equal annual temperature; these he called *isothermal lines.* This illustrious traveller also defined lines of equal mean winter temperature—*isochimenal lines,*—and those of mean summer temperature—*isotheral lines.* To give but one example of a line of equal mean annual temperature, let us take that which includes London, or gives a mean temperature of 50°: it may be mentioned that, cutting the mouth of the Oregon, it crosses the American continent a little to the north of Boston, curves upwards in crossing the Atlantic, passes over the southern portion of Ireland, through London, across the European continent in a slowly descending line, passes a little to the north of the Caspian Sea, and over Asia to the north of Pekin.

Thus, across the surface of our planet, we discover the variations of heat determining the distribution of vegetable, and, to a great extent, of animal life; this being due to the caloric received as solar radiations.

As the air increases in tenuity its capacity for heat becomes greater, and hence the extreme degree of cold experienced in ascending to great heights in the atmosphere. Regulated by this, we have a certain line of elevation, above which the snow never melts; this is called the *snow line,* or *line of perpetual snow.* This, of course, varies with the position of the spot as it regards the apparent path of the sun, and the modifying influences of currents as regulated by the disposition of land and water. Proceeding from the north or south towards the equator, the line of perpetual snow constantly ascends. The following are a few of the heights of the snow-line, as ascertained in various parts of the globe:—

Cordillera of Quito . . .	16,620 feet.
Cordillera of Bolivia . . .	17,070
Cordillera of Mexico . . .	15,020
Sikkim Indian side of the Himalayas	15,000
The Thibetian slope of the Himalayas	16,000
Caucasus	10,870
Pyrenees	8,950
Alps	8,760
Carpathians	8,500
Altai	6,400
Norway, interior of . . .	5,400
Norway, coast of	2,340

The upper limits of the snow-line cannot be ascertained, since we are not able to ascend to such a height as to be beyond the limits of aqueous vapour. Water must, however, cease to exist in the atmosphere at no very great distance from the earth, as evaporation must be suspended by the absence of a sufficient amount of heat.

At a certain depth beneath the surface of the earth, a line of equal temperature prevails, there being no alteration during the summer or the winter seasons; this depth, however, increases as we proceed from the equator towards either pole, and this, called the *chthonisothermal line*, also takes the curves indicated by the form of the surface,—curving upwards under a mountain, downwards under a valley. With an increase in depth from the surface of our planet, we have a gradual increase of temperature; the observations which have been made in our deep mines giving the following results:—

The mean temperature of the climate being	50°
At 59 fathoms from the surface the temperature of the rock is . . .	60
At 132 fathoms	70
At 239 fathoms	80

being an increase of 10° at 59 fathoms, or 1° in 35·4 feet, of 10° more at 73 fathoms deeper, or 1° in 43·8 feet; and of 10° more at 114 fathoms deeper still, or 1° in 64·2 feet. By this is indicated an increase of one degree of heat for about every fifty feet of depth, to the depth to which these observations have been extended; but it may be inferred, from a careful consideration of the rapidly diminishing rate of increase, that beyond a certain depth no elevation of temperature can take place.

If this subterranean heat was due to the influence of a *central fire* (which has long been a favourite hypothesis), we should certainly have a reverse order in the rate of increase in thermic action, to that which has been observed. Every extended series of observations appears to contradict the hypothesis of a *central fire*, and to prove that the increase of subterranean temperature is due to the absorption of calorific matter by the surface, and the gradual conduction of it by the masses of the rocks to a considerable depth. It is also found that rocks of different characters vary at the same depths in temperature, at whatever depth the experiment has been made. In all probability, the very high temperatures which are known to exist in certain localities, may be referred to the caloric liberated by chemical action. Volcanoes have been referred to this cause; and, although the view which is now generally entertained is opposed to this idea, there does appear to be so large an amount of evidence of a mineralogical character, which may be brought to support it, that it should not be too hastily rejected.

The phenomena connected with the evolution of caloric under the influences of chemical action, appear rather to belong to that peculiar branch of natural philosophy which is embraced by chemistry, than to physics, using the term in its strict sense. The instances of spontaneous combustion which from time to time occur, however, involve both physical and chemical causes; for the first action is due to the condensation of atmospheric air on the surfaces of the porous masses: by which a large amount of heat is rendered sensible, and this sets up that slow combustion,—called *eremacausis* by Liebig, or combination of oxygen with the organic matter,—which eventually passes into a more rapid state, producing actual fire. In the process of respiration, and also in that of digestion, we have heat produced by a similar process; the oxygen combining with the carbonaceous matter of the animal system.

Caloric, both solar and terrestrial, assumes a *radiant* condition, and in that state of mobility obeys the same laws as light: *the intensity of radiation diminishing as the square of the distance increases.*

Every one standing at a distance from a mass of heated metal, or even in front of a common fire, must become sensible of *calorific rays* passing off into space from the surfaces of the heated bodies. Different substances present various degrees of power for *emitting*, *reflecting*, *absorbing*, and *transmitting* rays of heat. These phenomena have been ably investigated by Leslie and Melloni, to whom we are chiefly indebted for the present state of our knowledge of *Thermotics*, or the science of Radiant Heat.

If a concave metallic mirror, such as *n* or *p* (Fig. 194), is taken, and a flame *a*, or an iron ball *b* made red-hot, be placed at a certain distance from its centre,—that is, in its focus,—the rays are collected in the reflector, as shown in the drawing, and radiated off from it in right lines. If we place a thermometer at the point *a* instead of the flame, the hot ball being in the focus of *p*, it will rise with great rapidity, showing the influence of radiant caloric. If we place a small piece of phosphorus at *a*, it will be inflamed by the rays passing from *p* and concentrated by *n* upon that point.

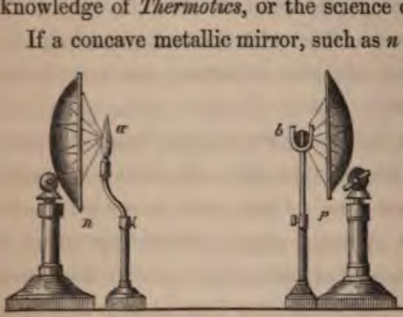


Fig. 194.

If, instead of the red-hot ball *b*, a lump of ice be placed there, the thermometer being at *a*, this instrument will show a diminishing temperature, as if cold had been radiated upon it; and this experiment has been, indeed, brought forward as evidence of *cold* being a substantive entity. In this case, however, the warmer body—the thermometer—radiates in the same way as the red-hot iron did, and this heat is reflected upon the ice.

Radiant heat is propagated with extraordinary velocity. It does not appear to travel at the same rate as light; but at about four-fifths of its speed, or about 164,000 miles in a second of time. It is not so refrangible as light (as is already explained), and this is probably due to its lower rate of progression.

The power of any body to *radiate*, or throw off caloric from it, has been investigated by Leslie in the following manner. A cubical vessel of block tin was procured; one side was brightly polished, another dimmed by scraping, a third covered with a glass plate, and a fourth blackened with lamp-black. The vessel was then filled with boiling water, and a delicate air thermometer placed at equal distances from either side. In this way Leslie determined the radiating powers of the following bodies to be:—

Lamp-black . . .	100	Red Lead . . .	80
Water (estimated) .	100	Plumbago . . .	75
Writing paper . .	98	Tarnished Lead . .	45
Rosin	96	Clean Lead . . .	19
Crown Glass . .	90	Polished Iron . .	15
China Ink . . .	88	Tin, Gold, Silver, and Copper . .	12
Ice	85		

A simpler form of the experiment was made by Rumford, and similar results obtained. Vessels of similar shapes and capacities were filled with liquids at a known temperature, and their rate of cooling noted. A blackened tin globe cooled a certain number of degrees in 81 minutes; a bright one took 156 minutes to cool to the same extent; a naked brass cylinder in 55 minutes cooled ten degrees, but when cased in linen it occupied 36½ minutes in losing the same amount of heat.

Bright vessels radiate heat feebly, therefore all vessels intended to retain their heat should be of brightly polished metals; and steam-pipes, if brightened along the whole of their course, would lose much less heat than they do, as they are commonly used, in their rough and dark state as originally cast; and if blackened when they reach the apartment they are intended to warm, the radiation would then be very great. In practice, however, radiation is usually prevented by clothing the pipes thickly with felt, or some other bad conductor of heat.

The power of *reflecting heat* varies as greatly as does that of radiating, with different bodies. The reflection of heat takes place from the *very surface* of the body, whereas radiation is rather the consequence of a certain thickness of the superficial mass. The most complete reflection is that from bright metallic surfaces; Leslie supposes the greatest reflection to be from brass, but Melloni and Nobili fix mercury and copper as having the highest power for reflecting caloric. By using different polished surfaces to reflect the heat of a common fire upon the face, we have an empirical method of arriving at approximate results as to their reflecting power. Leslie gives the following as the reflecting powers of a few substances :—

Brass	100
Silver	90
Tin-foil	85
Steel	70
Lead	60
Glass	10
Glass, waxed	5

The *absorption* of caloric varies with almost every form of matter; its molecular constitution, condition of surface, and colour, materially modifying the results. A very simple method of illustrating this, is to take a sheet of window-glass, and blacken the half of one side of it; place this in front of a fire, the blackened side towards it; after a short time, if the hand is placed against the naked side opposite to the blackened portion, it will be found to be much warmer than the other part. Franklin made an interesting experiment, by placing pieces of cloth of different colours on snow in the sunshine, and he found that the darkest pieces always sank the deepest into the snow, by the absorption of a larger portion of caloric.

By the experiments of Leslie and Ritchie—which have been to a great extent, but not entirely, confirmed by Melloni,—it is shown that the absorptive power of a body is inversely as its reflecting power, but directly as is its power of radiation.—*Bodies radiating heat quickly, become sooner heated when exposed to calorific radiations, than those bodies which radiate slowly.* Upon this fact is established Prévost's *theory of exchanges*, or, in other words, the extension to heat, of the theory of the equilibrium of forces, which appears to hold true for every condition of physical phenomena.

Upon a consideration of these facts, it will be evident that every substance in Nature is, according to its molecular constitution, and surface conditions (as it regards mechanical structure and colour), constituted to be for itself a measurer of the quantity of caloric which it shall absorb, and of that which it shall retain. Hence, during the day, every differently coloured flower in the garden, the grassy bed and the gravel walk, every variety of metal, or wood, or stone, exposed to solar influences, will present a different temperature; and during night, as these bodies part with their caloric at different rates—radiate unequally—they will exhibit varying degrees of coldness, and unequally condense upon their surfaces the dew of evening.

Mr. Six first pointed out, that on clear and dewy nights he always found the mercury lower in a thermometer laid on the ground, than in a similar instrument placed six feet above it. Dr. Wells subsequently followed up this investigation, and published an essay on the phenomena of dew, which will always be regarded as a pattern of inductive philosophy.

Dew is caused by the condensation of the moisture suspended in the air, upon any surfaces colder than the air with which it is mixed. A glass of cold water is brought into a warm room, and it very quickly becomes covered on its outer surface with moisture, condensed from the surrounding atmosphere. Those bodies which radiate caloric with the greatest rapidity, cool the quickest, and hence are covered with dew sooner than substances which radiate slowly. A very few degrees of difference of temperature are sufficient to determine the deposition of dew; therefore it will be understood, that any causes interfering with nocturnal radiation will very quickly determine its condensation, or the contrary. Thus, the formation of clouds, by obstructing radiation from the earth, or rather by radiating heat back to the earth, and establishing an equilibrium, prevents the surface from cooling, and the formation of dew is retarded.

Since all edges and points part with their caloric more freely than other portions of the same surface, we find these are always the first covered with dew or hoar-frost. The following quotation from Dr. Wells on Dew is highly instructive:—

"I had often smiled, in the pride of half-knowledge, at the means frequently employed by gardeners to protect tender plants from cold, as it appeared to me impossible that a thin mat, or any such flimsy substance, could prevent them from attaining the temperature of the atmosphere, by which alone I thought them liable to be injured. But when I had learned that bodies on the surface of the earth become, during a still and serene night, colder than the atmosphere, by radiating their heat to the heavens, I perceived immediately a just reason for the practice which I had before deemed useless. Being desirous, however, of acquiring some precise information on this subject, I fixed perpendicularly, in the earth of a grass-plat, four small sticks; and over their upper extremities, which were six inches above the grass, and formed the corners of a square whose sides were two feet long, I drew tightly a very thin cambric handkerchief. In this disposition of things, therefore, nothing existed to prevent the free passage of air from the exposed grass to that which was sheltered, except the four small sticks, and there was no substance to radiate downwards to the latter grass except the cambric handkerchief. The sheltered grass, however, was found nearly of the same temperature as the air, while the unsheltered was 5° or more colder. One night the fully exposed grass was 11° colder than the air; but the sheltered grass was only 3° colder. Hence, we see the power of a very slight awning to avert or lessen the injurious coldness of the ground."

Solar radiations of caloric, and those from terrestrial sources, present some remarkable differences: this may be illustrated by Dr. Franklin's experiment. A piece of black cloth placed on snow in the sunshine rapidly sinks into it, by becoming warm from the absorption of caloric. If, however, we screen the black cloth from the direct rays, and reflect them from a metallic mirror, a coutrary effect will take place, and the snow around the cloth will melt, and leave it standing upon a column of snow. The cause of this has not been satisfactorily explained. Delaroche has also shown that the rays from an ordinary fire will not permeate a sheet of transparent glass, which offers but little obstruction to the passage of the solar heat-rays: but if the fire is excited up to a white heat, its radiations pass the glass freely; and those which have passed one sheet of glass, very readily permeate a second.

Transparent and variously coloured bodies have different degrees of *transparency to heat.* Melloni has proposed a nomenclature for this branch of the science, which is useful as a means of correctly marking effects. *Diathermasy* (from διὰ, *through,* and θερμάω, *to heat*) being employed to express calorific transparency; and *Adiathermasy,* to signify *calorific opacity.*

Gaseous bodies and a vacuum are perfectly *diathermous,* and the following bodies have different degrees of *diathermasy*:—

Transparent rock-salt *transmits, out of* 100 *calorific rays*	92
Flint Glass	67
Calcareous Spar	62
Crown Glass	49
Green Tourmaline	27
Sulphuric Ether	21
Crystallized Sulphate of Lime	20
Alcohol	15
Alum, crystals of	12
Water	11

It has already been mentioned that black mica, obsidian, and black glass, are opake for light, but transparent for heat; that glass stained with oxide of copper in combination with a layer of water, though perfectly transparent for light, is opake for heat, or adiathermic. Among coloured fluids similar differences, many of them of a most remarkable character, may be detected; and upon the study of these Melloni has founded a new branch of science, which he terms *Thermochroology* (from θέρμη, *heat*, χρόα, *colour*, and λόγος, *discourse*), or, the doctrine of coloured heat. It is found that fluids of different colours cool unequally: a yellow-coloured fluid always freezes before any other, and it is the last to be warmed by calorific radiations. This delicate branch of science is, notwithstanding all that Melloni has done for it, open for a very extensive and searching examination.

In connection with this class of investigation may be included the phenomena of *thermography*, or the delineation of a design upon one surface on to another with which it is placed in juxtaposition, even in the dark. These curious results were attributed, by Professor Moser, of Königsberg, to *invisible light*; but my own researches have most fully proved that these images are entirely due to thermic radiations. I found that, to obtain a good image, the superposed body must be composed of a different material from the impressed plate. I placed upon a plate of copper, blue, red, and orange-coloured glasses, pieces of crown and flint glass, mica, and a square of tracing paper: these were allowed to remain in contact for half an hour. The space occupied by the red glass, when the plate was subsequently exposed to the action of vapour, was well marked; that covered by the orange less distinct; but the blue glass left no impression; the shapes of the flint and crown glass were well made out, and a remarkably strong impression where the crown glass rested on the tracing-paper; but the mica had left no trace of an impression. For an extensive set of similar experiments, the reader is referred to the author's 'Researches on Light.'

Heat, it has been seen, obeys many of the laws which regulate the motion of light. It is reflected and refracted after the same manner; and is susceptible of that very remarkable change of state which is known by the name of polarization. The explanation of this is difficult, requiring a previous amount of scientific education on the part of the reader, in this particular department, which cannot in all cases be expected. The phenomena of polarization will be more fully dealt with in the next section, the phenomena of luminous polarization being of a more striking character than those of heat. It may be described, in general terms, as a power of turning the ray of heat half round; and it is regarded as proving that the influence of the *lateral vibrations* are different from the onward waves in calorific propulsion.

The engraving (Fig. 195) represents the arrangement of Melloni's thermo-electric pile, as given in Müller's 'Physics.' The pile of bismuth and antimony, carefully blackened at both ends with lamp-black, is placed at *p*; the coverings *a*, *b*, serving to keep off currents of air, and to screen from lateral radiations; *c* is the galvanometer;

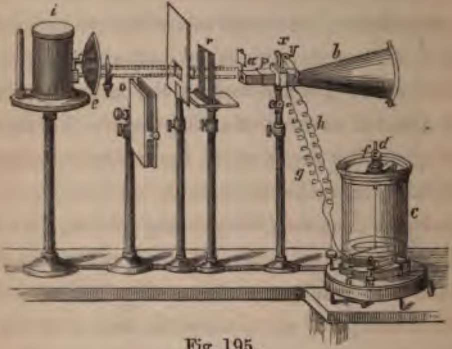


Fig. 195.

f, *d*, an arrangement for adjusting the astatic needles, and *n*, *m*, the binding screws which connect the wires *g*, *h*, which are also connected with the two ends of the pile at *x*, *y*; *r* is a stand upon which any transparent screen is placed; *i*, *e*, and *o*, show the sources of heat and the means of reflecting or radiating it; the other stands being merely screens which can be used at any moment necessary, for cutting off the rays easily, and thus, by allowing the needles to return to zero, to repeat and correct any set of experiments. By such an arrangement as the above, the Italian experimentalist has been enabled to determine with great accuracy the amount of heat radiations which will permeate transparent bodies, the influence of colour, and the very beautiful phenomena of calorific polarization.

One other condition of heat alone remains to be mentioned. Boutigny has shown that bodies exposed to very high temperatures do not obey the ordinary laws with regard to caloric. Thus, water projected into a red-hot crucible will not boil so long as the red heat is maintained; the highest temperature to which it will arrive being about 130° Fahr. Spirits of wine and ether evaporate less rapidly in intensely heated vessels than in such as are much colder. If a metal sieve is made red-hot, and water poured into it, the water will not flow through it so long as the wires continue incandescent; allow them to cool, and the fluid rushes through the meshes with great rapidity. This has been called the *spheroidal state of bodies*, from the circumstance that all fluids form themselves, when projected into incandescent vessels, into spheroids, and roll about with a very peculiar motion.

At high temperatures even chemical action is suspended: acids and alkalies may be thrown together into an intensely heated platinum crucible, they will not unite, but, forming themselves into separate spheroids, they roll around, singularly repelling each other. Following out this very remarkable class of investigations, M. Boutigny, and Professor Plucker, of Bonn, have shown that the moisture on the skin is sufficient to protect it from the influence of intensely heated masses. Thus, liquid iron flowing from a furnace may be cut with the naked arm; and the hand may be plunged into baths of melted bronze—provided they are maintained at a degree of heat sufficiently elevated—without any injury. From these results it would appear probable that caloric passes into a purely radiant state at very high temperatures. Under intense degrees of excitement, it ceases to produce the effects of heat as they are ordinarily known to us: a new condition is produced.

The decomposition of water by heat, as effected by Mr. Grove, appears to be an exemplification of a similar condition to that of the spheroidal state. A metal oxidizable with difficulty—platinum—is made white-hot, in contact with water, or melted and dropped into that fluid. The result is the liberation of a gas, which is found, upon examination, to be oxygen and hydrogen, in the exact proportions in which they form water. Here, caloric breaks up the chemical affinity which holds the gases combined as water; and in the experiments of M. Boutigny we find it entirely preventing the exercise of affinity. Physical phenomena of a most novel character, demanding the searching attention of the experimental philosopher, are involved in those new discoveries, which prove that matter may be made too hot to burn.

CHAPTER VIII.

LIGHT AND ACTINISM.

THE cause producing luminous phenomena is, notwithstanding the extensive experimental investigations which have been prosecuted in this department of physical science, still involved in considerable doubt. The Newtonian theory supposed light to be a positive entity, emitted in infinitely fine particles from the sun, which travel to the earth and the other planets with enormous velocity. The theory of Huyghens, which was rendered more intelligible by the genius of Dr. Young, and which has since his time been very generally received among philosophers, supposes the existence of an imponderable medium disseminated through the universe, and interpenetrating all kinds of matter. The evolution of light is thought to be due to undulations, or wave-movements, through this ether. What has been already said in relation to vibratory progression in the case of sound, applies equally to the undulatory hypothesis of light. Another theory, referring all luminous phenomena to electrical influence, has been propounded; but it has not been deemed satisfactory.

Every experiment in physical optics appears to prove that the mode of progression is undulatory; but it must not be forgotten, that the assumption of an imponderable ether is unsupported, of necessity, by any real evidence. The mathematical investigations of the phenomena of light, certainly go to support the views entertained by Huyghens and Young. The researches of Fresnel, Fraunhofer, Herschel, and others, show that a large number of facts can be explained upon the undulatory hypothesis: at the same time a great many very remarkable phenomena are by no means elucidated; and the corpuscular theory of Sir Isaac Newton, developed by Laplace and Biot, and supported by Brewster and Brougham, is capable of affording an explanation of some luminous effects which do not appear to be the result of undulations.

Lord Brougham has been lately engaged in the investigation of a class of phenomena which was first noticed by Grimaldi—the production of coloured fringes around the shadow of an opake body. These researches show that a ray of light is bent out of its right line, whenever a solid body (as a knife-edge) is made to cut the edge of the beam. The action of solid surfaces upon fluids and gases has been already mentioned; and it would appear that in a similar manner they possess the power of *attracting*, or *condensing*, as is shown by *bending*, the ray out of its path. The experiment is a very delicate one, requiring very perfect apparatus; but the result is undeniable. Lord Brougham has shown that when a ray is once bent inward by the knife-edge—*inflexed*,—it is no more capable of being inflected, it has undergone a very remarkable change; in the same manner, if a ray is *repelled* by a solid body—*deflexed*,—it can be no further deflected by the interposition, on the same side of the ray, of any solid substance:—certainly these results appear to indicate the existence of an exceedingly refined form of matter. Whether it may emanate from the sun, or merely be excited by the influence of some solar force, are questions which are yet to be resolved by the researches of the experimentalist and the reasonings of the philosopher.

Light renders external objects visible by radiating from their surface the luminous agent, which, by exciting the nerves of the optic organ, conveys the sensation to the brain. The eye is a most beautifully contrived apparatus. It is nearly spherical in form, and composed, in the first place, of a tough and opake membrane, *b b*, called

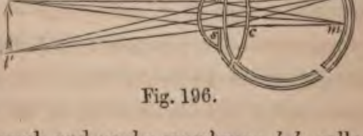


Fig. 196.

the *sclerotic coat*, constituting the white of the eye; lining this is the *choroid membrane*, which terminates near the iris in a series of filaments, forming the *ciliary ligament*. The *cornea*, *s s*, is an exceedingly tough membrane, although clear and transparent:—it is firmly united to the sclerotic coat; fixed into it, indeed, like the glass into the case of a watch, and supported by several adhering layers. In the centre of the cornea is a circular opening, the *pupil*, and within it is, *c c*, the *crystalline lens*, a transparent capsule containing the *vitreous humour*. Within the choroid coat is a very delicate black pigment, and immediately within this is the *retina*, which forms the innermost coating of the visual chamber. The retina is a delicate reticulated membrane, which appears to be an extension of the optic nerve. The retina has usually been regarded as the seat of vision; but Mariotte, who discovered that the base of the optic nerve was incapable of impressing any sensation of light on the brain, is disposed to believe that the choroid coat is rather to be considered as such; particularly as where there was no choroid coat, there, he discovered, was no distinct vision.

Without entering into the refined considerations which belong to the physiology of vision, we may safely decide that the images of external objects are painted on the retina. This may be proved by taking the eye of any recently killed animal, and cutting a small hole in the upper part of the ball, looking in upon that delicate membrane. It will be seen that the mechanical arrangement of the optic organ resembles in many particulars the camera obscura of Baptista Porta. This instrument, in its original state, was nothing more than a dark room, with a very small opening, into which was fitted a lens. If we make such an arrangement, and hold, a few feet behind the hole, a sheet of white paper, a very perfect image of any external object will be delineated upon it, as shown in the annexed woodcut. The usual mode of constructing the camera obscura, is to place a lens in an opening made in a dark box; and where it is intended that the effect should be exhibited to several spectators at once, a mirror is placed at the termination of a tube on the top of a dark room: the mirror, being placed at an angle of 45° to the horizon, reflects the landscape down through a large lens on a table, the concavity of which agrees with the convexity of the lens.

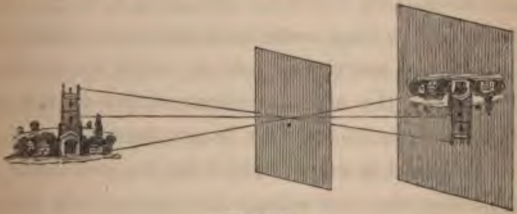


Fig. 197.

In the eye is formed a similar inverted image, and, relatively to the intensity of its light and colours, a degree of irritation or excitement is set up, by which the sensation is conveyed to the brain. Sir John Herschel has speculated on the probability that the sensitive table of the eye is in a similar condition to the sensitive surface of a daguerreotype plate, upon which a photographic picture is impressed by the radiant power; that a kind of chemical change takes place, possibly in the pigment lining the choroid coat; and that, during this chemical change, a physical effect is produced in the organ of sensation.

Much difficulty has arisen in attempting to explain the phenomena of erect vision, and of single vision with a pair of eyes. The usual argument relative to the first difficulty is, that although the images formed in the eye are inverted, they are conceived to be erect from the circumstance that everything has always been viewed under the same conditions. This mode of reasoning necessarily involves the idea of a supplementary seat of vision, which sees the images on the retina; we have no evidence of any such, and it appears quite unnecessary that such an arrangement should exist. It must be remembered, that the sensation conveyed to the brain from that organ on which the actual picture is painted by light, is more of the character of mechanical impulse: the delicate nervous filaments are more or less excited according to the degree of light, and consequently to the intensity of colour; and this produces, by some mysterious process, a sensitive action, through which the mind receives a correct impression of external objects. It may be objected to this view, that it does not explain all the phenomena which are associated in optical perception. We are, in the act of seeing, made conscious of the *presence* of an object, sensible of its *form*; we see the three dimensions —*length*, *breadth*, and *thickness*,—and we faithfully appreciate its *size*, *colour*, *movement*, and *distance*. Some of these are the result of habit; we are, indeed, *taught* to estimate the distance of a body from the eye. All the other points admit of explanation under the view taken, as they all produce variations in the quantity of light which excites those material organs to which the property of *seeing* belongs. The second question, as to single vision with a pair of eyes, appears to be answered by the fact, that the optic nerves intersect each other at a certain point, and, therefore, from that point a single impression is conveyed to the brain.

The stereoscope of Professor Wheatstone familiarly illustrates this. This instrument consists of two mirrors, the backs of which are inclined to each other at an angle of 90°. It will be obvious that if two pictures of the same object are placed at a little distance in front of the mirrors, we have two reflected images. If, however, we bring the nose close to the edge at which the mirrors are united, and thus look with an eye into either glass, the two are resolved into one; and the resulting image appears of three dimensions. This is very completely effected if the precaution is taken of preparing the drawings so that they represent the object as seen by either eye. If we look at any object first with one eye and then with the other, we shall convince ourselves that we do not see exactly the same set of lines, at the same distances from each other. If we place two candles, for example, in such a position, that when they are looked at with the right eye, one covers the other, we shall find when we close the right eye and look at them with the left, that the hinder candle is no longer screened by the front one, but will be seen about an inch to the left of it.

We may produce double vision if we so set the eyes that their axes may meet either beyond or before the object. On this subject Sir David Brewster, who has devoted much attention to the examination, writes—"Although an image of every visible object is formed on the retina of each eye, yet when the two eyes are capable of directing their axes to any given object, it always appears single. There is no doubt that, in one sense, we really see two objects, but these objects appear as one, in consequence of one exactly occupying the same place as the other. Single vision with two eyes, or with any number of eyes, if we had them, is the necessary consequence of the law of visible direction. By the action of the external muscles of the eye-balls, the axis of each eye can be directed to any point of space at a greater distance than four or six inches. If we look, for example, at an aperture in a window-shutter, we know that an image is formed in each eye; but, as the line of visible direction from any point in the one image, meets the line of visible direction from the same point in the other image, each point will be seen as one point, and, consequently, the whole aperture seen by one eye will coincide with, or cover, the whole aperture seen by the other. If the axes of both eyes are directed to a point beyond the window, or to a point within the room, the aperture will then appear double, because the line of visible direction from the same points in each image do not meet at the aperture. If the muscle of either of the eyes is unable to direct the two axes of the eyes to the same point, the object will in that case also appear double." The inability of one eye to follow the motions of the other, is frequently the cause of *strabismus*, or squinting; this may be the result of habit, of imperfect power in one eye, or of some defect in the muscular movements. The cure of squinting is to be effected by constantly directing the eye in such a manner that the axes shall coincide.

Every impression, according to the intensity of its effects, remains for a certain length of time on the retina, and a measureable period is necessary to produce the impression. If, when travelling at great speed on a railroad, we look at any distant objects through railings or upright posts placed by the side of the road, although those opake bodies continually obstruct the sight, they produce no effect on the eye; the whole appears transparent, and the distant country is as distinctly seen as if these had not been interposed between it and the eye. If we take a large disc of metal, and fix it on an axle with such adjustments that it can be made to revolve with great speed, and through a very small slit made in one part of the disc, look at a candle, or any bright object, it will not disappear when the disc revolves at its high velocity; although so large a portion of the opake metal for some time prevents the passage of the light to the eye. Numerous similar experiments may be tried, all of which tend to prove that a certain period of time is necessary, after the eye has been excited, for it to recover its original state of rest. The persistence of impressions on the retina, has proved a very favourite field of investigation. M. D'Arcy found that the light of a glowing coal, moving at the distance of 165 feet from the eye, maintained its impression on the retina during the seventh part of a second.

Light is produced under several different conditions. The sun is, to this earth, the most remarkable source of the luminous principle; and the light of the fixed stars appears to be of a precisely similar nature to that which we receive from the centre of our system.

Under the influence of chemical change light is developed, as in the processes of ordinary combustion;—the light from burning coal in our fires, the light of lamps, ignited gas, or candles. By electrical excitation, light of great intensity is produced; but notwithstanding the attempts which have been made to apply it usefully, there appear to be but very small grounds for hoping that these may prove eventually successful. The irregularity in the illuminating power, the want of diffusion in the light, which, notwithstanding its intensity, occasions a very rapid decay of radiations with distance, and the expense at which it is produced, appear to stand in the way of the useful introduction of the electrical light.

By friction, heat is produced, and when a certain temperature is obtained (about 1,000° Fahr.), the bodies become luminous; but there are some in which the phenomenon of phosphorescence is produced at a very low temperature by attrition.

Phosphorescence,—resulting from electricity, from the influences of the solar radiations, and from animal excitement,—must be regarded as another, and a peculiar, condition of luminous excitation.

Light renders all external objects visible, its rays being reflected from the surface to the eye, the amount of light reflected depending on the structure of the surface and its colour. Some bodies are *diaphanous*, or transparent to light, as the air, water, glass, &c., but no perfectly transparent body exists: any substance which allowed all the light to pass through it would be invisible. If we let a pencil of light into a dark room, so that it falls upon a vessel of water, a considerable portion of it will permeate it, but some will be reflected back from the surface.

Light is propagated in right lines from every luminous point, every such line being called a ray of light. That light moves in undulations appears highly probable; but because a wave motion is admitted, it does not follow that the theory of ethereal undulation, as the cause producing luminous effects, is adopted. In the present state of the inquiry, it appears most important, notwithstanding the array of names in favour of the theory of vibration, to hold the judgment suspended.

The *degree of illuminating power* of any body depends upon—the intensity of exciting power in the luminous body,—the distance of the illuminating body,—the amount of *absorption* which the rays undergo in traversing the intervening media,—and the angle at which the rays fall upon the surface.

The illuminating power of the planets, the Earth being 1, is as follows :—

Earth	1·00
Venus	2·00
Mercury	6·00
Mars	0·44
Jupiter	0·04
Saturn	0·01
Uranus	0·0025

It will be understood that these illuminating powers of the planets depend upon the distance these orbs are from the sun and from our own earth.

In artificial light, the illuminating power is in exact ratio to the quantity of solid matter which changes form. Pure hydrogen gas has a very small illuminating power; but if, by passing it through any fluid containing carbon, as naphtha or spirits of turpentine, it is made to take up a portion of this element, it burns with great brilliancy.

The intensity of light is measured by *photometers*.

These are of very various constructions, but none of them appear to answer their intentions perfectly. A very simple contrivance, by which the relative illuminating powers may be ascertained, is, to allow the shadows from a single object to fall upon a white screen, and then remove the sources of light from or towards it, until all the shadows are of the same depth: the distances at which the illuminating bodies are from the screen, express the relative intensity of the light of each.

The sun produces the most intense light of any body with which we are acquainted. Dr. Wollaston calculated that it would require 20,000 millions of the brightest stars, such as Sirius, to equal the light of the sun, or that that orb must be 140,000 times farther from us than he is at present, to be reduced to the illuminating power of Sirius; the same authority has determined that moon-light is 801,072 times weaker than sun-light.

Römer found, from observations on the occultation of one of Jupiter's satellites, that light moves through space at the rate of 192,000 miles in a second of time; and Sir William Herschel has calculated that it travels in a vacuum with a velocity equal to 192,500 miles in that period. Light takes eight minutes and thirteen seconds to come from the sun to our earth, and nearly three hours to travel from our planet to Uranus. The following calculation has been made, to familiarize the mind with this high velocity. Light moves through a space equal to the circumference of our globe, in the eighth part of a second:

a flight which the swiftest bird would not perform in three weeks. A locomotive engine on a railroad has travelled rather more than a mile a minute; now it would require 137 years to go from our earth to the sun at that speed; and yet the illuminating rays pass from that orb to us in a little more than eight minutes.

M. Fizeau has determined the velocity of artificial light by a very ingenious contrivance. A disc, carrying a certain number of teeth upon its periphery, was made to revolve at a known rate: placing a tube behind these, and looking at the open spaces between the teeth, they become less evident to sight, the greater the velocity of the moving wheel, until, at a certain speed, the whole edge appears transparent. The rate at which the wheel moves being known, it is easy to determine the time occupied while one tooth passes to take the place of the one next to it. A ray of light is made to traverse many miles through space, and then pass through the teeth of the revolving disc. It moves the whole distance in just the time occupied in the movement of a single tooth to the place of another at a certain speed; this method gives a very close approximation to the results obtained by observation on the moons of Jupiter, or on the *aberration* of light.

By *aberration* is meant the difference between the real and the apparent places of the stars. As the light is proceeding from them, the earth is moving onward; consequently, they appear to be rather more backward than they really are in the direction of the earth's annual motion. A very pretty experiment, proving the velocity of light, is to paint the primary colours on a disc, which is made to revolve so rapidly, when connected with a multiplying wheel, that the colours are completely blended; neither of them being enabled to produce an impression on the retina. While the disc is revolving at this high velocity, a brilliant spark is taken from a Leyden jar, so that the disc is illuminated by it, and it then appears to stand nearly still. The rapidity of the light is such, that the colour *a* cannot change to the place of the colour *b* next to it, during its passage, notwithstanding the immense speed at which these colours are moving.

The science of Optics divides itself into two parts:—*Catoptrics*, or the laws of reflection; and *Dioptrics*, or the laws regulating transmission.

Any substance reflecting light is called a *speculum*, or *mirror*. The latter term is usually applied to glass which is covered with quicksilver on the back, or on which an actual coating of silver is precipitated, as is now sometimes effected; the name of speculum being applied to metallic mirrors—these are made of either silver, or steel, or a mixture of tin and copper. They may be either *plane*, *concave*, or *convex*. Whenever a ray of light falls upon any surface, whether *curved* or *plane*, the angle of its reflection is equal to the angle of its incidence.

In *plane mirrors*, reflection only inverts the incident beam of light, shifting its point of convergence or divergence to the opposite side of the mirror. The reflection from curve mirrors requires a more particular attention.

In *concave mirrors*, any rays which fall upon their surface are reflected to a converging point, at variable distances in front of the mirror, according to its curvature and to the direction of the rays impinging upon it: this is called its *focus* (or *fire-place*). Such mirrors are employed for concentrating the sun's heat-rays to a point, by which means the most intense calorific action can be produced: these are called *burning mirrors*.

The image of any object at some distance from the mirror is represented in its focus, and by this means numerous tricks of natural magic are produced. A concave mirror is hidden from the observers, while opposite to it, also hidden, but strongly illuminated, is placed some striking object; this is reflected to the focal point, and seen, as it were, painted on air. These *physical spectres* may be rendered exceedingly effective.

If a source of light is placed in the focus of a concave mirror there will be no image, but a brilliant reflection in parallel lines from every point of its surface. Of this kind are the reflectors in lighthouses; of the former variety are the specula of reflecting telescopes and some optical instruments.

All the rays which fall on the surface of a *convex mirror* will diverge on being reflected. The image seen in a concave mirror is always magnified, whereas in a convex one *it is* very considerably reduced. The focus of a convex mirror is an imaginary point behind the surface, called the *virtual focus*, at which point objects are seen.

We have now to consider that section of optical science distinguished by the term *Dioptrics*, and which treats of the progress of light through transparent bodies.

When a ray of light passes out of air into water, or even from spirit into that fluid, or from water into oil, it is seen to deviate from the right line, it undergoes *refraction* (a term signifying *breaking back*). If a rod is placed upright in still water, it appears bent, and sometimes even broken, owing to this peculiarity of the luminous rays.

The law of refraction may be discovered in the following manner. Fig. 198 represents two media of different density—air and water. Let a ray, *a b*, fall obliquely upon the surface of the fluid, it is refracted, and deflected into the line from *b* to *f*; *b* is called the *point of incidence*; *d d* is the perpendicular, *c a* the sine of the angle of incidence, and *d a* the sine of the angle of refraction; the ratio of the first to the last being the ratio of the ray's refraction. When light passes out of a rare into a denser medium—as from air to water, as in the example given—the angle of incidence is greater than the angle of refraction; but when it passes from a dense into a rare medium, as from water into air, the angle of incidence is less than the

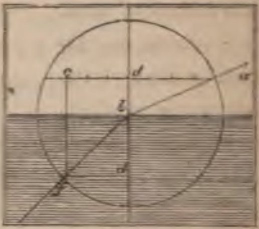


Fig. 198.

angle of refraction. The ray of light is bent towards the perpendicular in the first case, and from the perpendicular in the latter example.

A pleasing mode of illustrating this, is to place a silver coin, *m*, at the bottom of a basin (Fig. 199). The rays, *i i*, proceeding to the eye from the silver surface, render the coin visible. The point *a*—the eye—is then moved farther back, so that the edge of the basin obstructs the direct rays, and of course the coin is no longer seen. If an attendant carefully pours water into the basin, so that the object is not moved, it will presently, as the water rises in the basin, become again visible. This arises from the refraction of the rays by the water; the image, indeed, appearing at *n* instead of at *m*. It is owing to this that the depth of the bed of a pond of pellucid water appears much less than it really is.

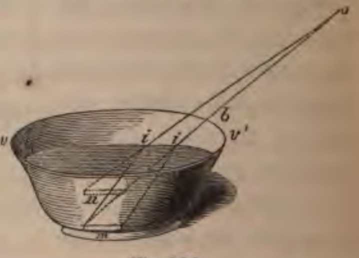


Fig. 199.

Different substances have different refracting powers, but no law has yet been discovered by which these appear to be regulated. It would appear that dense bodies have a greater refractive power than those which are more rare; but chemical composition materially influences refraction, and Sir Isaac Newton inferred that the *diamond* must be a combustible body from its very high refracting power; inflammable bodies refracting light more strongly than those which are non-inflammable. The following table exhibits the indices of refraction of a few of the more remarkable bodies:—

Vacuum	1·000000
Hydrogen	1·000138
Atmospheric Air	1·000284
Water	1·366
Crown Glass	1·500
Flint Glass	1·639
Sulphur	2·040
Phosphorus	2·224
Diamond	2·487
Chromate of Lead	2·936

According to the undulatory theory of light, refraction is due to an alteration in the velocity at which the ray of light travels. According to the corpuscular theory, it is accounted for on the supposition that different substances exert different attractive influences on bodies coming within their influence:—a highly refractive medium is supposed to exert a strong attractive force, while a weaker force is exerted by those in which the refractive power is less. Something like this is shown to prevail when a ray of light is bent over the edge of a solid body which cuts the line of its path.

The influence of atmospheric refraction in producing twilight has already been noticed (page 136). All the phenomena of the *mirage* are due to the same cause. Objects which are not ordinarily visible, appear to float upon the air; *and, frequently*, inverted images of them are seen, as though the refracted image was reflected in an under stratum of air. Captain Scoresby has given several very remarkable examples of these phenomena, in the Arctic regions; ships, a considerable distance beyond the visible horizon, being seen suspended in thin air. Many of the appearances which superstition has clothed with all the robings of a wondering imagination, are to be easily explained on the known laws of refraction. The *Fata Morgana* is of this character. These curious airy pictures appear to be due to a refraction of the rays in passing through aerial zones of different density, and to the reflection of images upon other masses of air.

We may imitate many of these phenomena of atmospheric refraction. If we look along a red-hot bar of iron, or a mass of heated charcoal, at some image a short distance from it, an inverted reflection of it will be seen. In a similar manner, if we place in a glass vessel fluids of different densities, so that they float one above another, and look at some word through these, it will be seen out of its true place in consequence of the refracting and reflecting powers of the fluids employed.

Haloes—the coloured rings seen around luminous objects—are due to this refracting power. These are called *parhelia* when they appear around the sun, and *paraselenæ* when seen around the moon. The phenomena of refraction as exhibited in the rainbow will be examined in a future page.

If we can find the inclination of the incident ray to that portion of the surface where the ray enters or quits the body, we may readily determine its refracting power. A ray of light falls upon a sheet of glass, and it is bent in passing through that dense body, but the emerging ray will be parallel to the direction of the incident ray; and thus we see bodies through sheet-glass in their true position.

Glasses whose surfaces are segments of spheres are called *lenses*: they are principally either concave or convex.

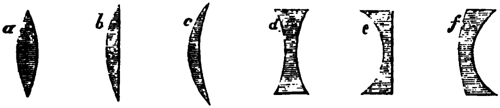


Fig. 200.

a is a *double convex* lens; *b* is termed *plano-convex*, having one side a plane and the other convex; *c*, which is formed of parts of two circles which meet, is called a *concavo-convex* or a *meniscus* lens; *d* is a *double concave*, *e* a *plano-concave*, and *f* a *concavo-convex* lens. The general operation of glasses of this kind may be gathered from the following brief description; the laws determining the kind and degree of refraction which they produce are too complicated for the present treatise,—these will be more effectively studied in the works of Herschel and Brewster, who have most fully investigated this subject.

The images formed by lenses will be best understood by reference to the accompanying woodcut (Fig. 201). A B is an object on one side of a lens, W V, but farther removed from it than the focal point F. The rays which proceed from A are united to a point at *a*, by passing through the middle of the lens; *a* being an image of A. In the same manner the rays from B pass through the centre, and form an image at *b*; thus the object A B is represented inverted at *a b*. The size of the image is regulated by the distance of the external object from the lens. If the object be removed more than twice the distance of the focus, the image will be nearer, and we obtain a diminished image; if it is approached nearer the glass, the image recedes, and is enlarged. In lenses of short focus, the images lie nearer the glass than in one of greater focal distance.

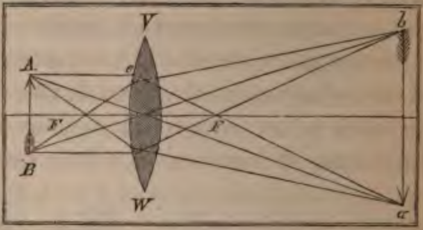


Fig. 201.

Let A B (Fig. 202) be any object nearer the lens than its focal distance; then the rays from it *diverge* on leaving the lens W V, and the eye placed at C, which is just at the

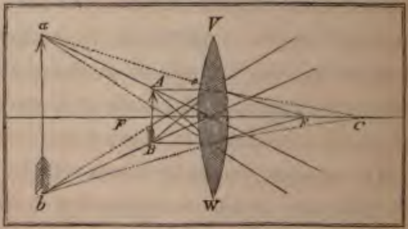


Fig. 202.

focal point, sees an image at *a b*. The object and the image lie within the angle *a o b*, but the object being nearest the glass we see the image magnified. In microscopes the images formed are of this kind.

The use and power of lenses may possibly be rendered familiar by the following easy considerations. An object, known to be a man or a tree, is seen at a certain distance indistinctly, the mere outline only is appreciated by the eye; as we approach more closely to it, all its details, one after the other, are developed, until the minutest lines are visible. As the object is removed from the eye its *apparent magnitude* is diminished; as it is approached towards the eye it is increased: thus, when brought near the eye, a small shot may be made to cover the view of a mountain; therefore, the apparent magnitudes of these bodies are equal under such conditions. A man stands at the distance of 100 measures from us, and we look at him through a lens of a certain focal distance, and his image, of the natural size, is seen distinctly. Now, if we place a lens having a focal length of one-fourth the distance between ourselves and the object, it may be seen that an image of precisely the size of the object would be produced behind the lens; and if looked at by the eye at a distance of six inches, it will be seen very distinctly, the image being apparently magnified in the proportion of 6 inches to 100 feet. We have supposed the distance to be 100 feet, and the focal length of the lens 25 feet; this produces an *image of the* natural size. If a lens of shorter focus is placed 75 feet from the object, and 25 from the eye, the image will only be one-third the size of the object; but by being brought near the eye its apparent magnitude is increased. The rule for ordinary telescopes is this:—Divide the focal length of the lens by the distance at which the eye looks at the image; and the result will be the magnifying power.

The *Telescope* was invented in the thirteenth century, and in all probability introduced into England by Roger Bacon. It consists of two convex lenses—the *object-glass* and the *eye-glass.* An inverted image of an object—as, for example, a star—is received on the object-glass, and magnified by the eye-glass. The Galilean telescope differs only from the astronomical telescope just described, in having a concave eye-glass instead of a convex one. Telescopes of these kinds were made by Huyghens and others, 136 feet long; it was with instruments 12 and 24 feet long, that Huyghens discovered the ring and the fourth satellite of Saturn.

Terrestrial telescopes differ from these only in an adjustment of lenses to see the object erect; this adjustment being merely the addition of eye-glasses, so that the inverted image formed behind the first is corrected by passing through another, and viewed through a third.

The reflecting telescope consists essentially of a concave mirror—*a speculum,*—the image in which is magnified by a lens. James Gregory first described the construction of such an instrument, and hence these have been called

Gregorian telescopes. Sir Isaac Newton appears to have been the first to construct such an instrument; the Newtonian telescope, made by Newton's own hands, being in possession of the Royal Society. The usual arrangement of reflecting telescopes is the large speculum at the bottom of a tube, in which the image is formed; this is received on a smaller speculum, placed at some distance from the former, and viewed by means of lenses. In Sir William Herschel's telescope the second speculum was not employed; the eye, by the aid of magnifying powers, at once viewed the image in the large speculum.

Sir William Herschel constructed 200 seven-feet Newtonian reflecting telescopes, 150 ten feet, and 80 twenty feet in focal length; at length he constructed his telescope forty feet long, and on the 27th of August, 1789, the day on which it was completed, he discovered with it the sixth satellite of Saturn. The speculum of Sir William Herschel's telescope had a diameter of 49½ inches, its weight was 2,118 lbs. The great reflecting telescope of Lord Ross has a speculum of seventy-two inches diameter. Mr. Nasmyth and Mr. Lassell have also constructed reflecting telescopes which are remarkable for their power rather than singular for their size, the specula being but twenty-four inches diameter, and twenty feet focal length.

The *Microscope* is nothing more than a lens, in the focus of which the object to be examined is placed. Little spheres of glass, formed by melting glass-threads in the *flame of a candle*, form the most powerful single microscopes. A *compound microscope* consists of two or more lenses, one of which forms an enlarged image of an object, and the others magnify that image. Much ingenuity has been expended in producing the greatest degree of power and distinctness of definition, but in all essential particulars the best instruments accord with the above brief description.

In describing these instruments, we have assumed that the rays refracted from spherical surfaces meet exactly in the focus. If an object is placed at an equal distance in front of a lens, to the length of the focus, it will be found that the best image is not formed at the focal point behind the lens; this is due to what is called *spherical aberration*. The curve of the lens is at unequal distances from the object and from the screen placed at the focal point, and hence, if one part of the image is perfect, another is less so, owing to this aberration, depending on the sphericity of the lens or mirror. By combination of lenses this may, however, be reduced to an almost inappreciable quantity. These points, depending on nice geometrical problems, will be found fully described by Sir David Brewster, in his treatise on Optics, or by Sir John Herschel, in his article on Light in the 'Encyclopædia Metropolitana.'

If a piece of Iceland spar is placed upon a sheet of white paper, on which we have previously made *one* black spot, *two* will be seen through the crystalline body. This is termed *double refraction*. Bodies possessing this property, divide into two portions the rays of light sent through them. The explanation afforded by the undulatory theory of light, which accounts more satisfactorily than any other for this class of phenomena, is, that the *ether* suffers an unequal division in the interior of those crystals which produce it; this division depending on some law of molecular arrangement determined by the crystalline forces. These two lines, or rays, are called *the ray of ordinary refraction*, and *the ray of extraordinary refraction*: one is supposed to pass the crystalline medium more rapidly than the other.

This leads us to a consideration of the phenomena of coloured light. White light, as emitted from the sun or any luminous body, or as excited by their influence, is composed, according to Sir Isaac Newton, of seven different kinds. The *compound* white light, as Newton supposed it to be, may be separated into its different parts by refraction and by absorption. The first method, *refraction* by the prism, was that employed by Newton. If a round hole is made in the window-shutter, *a b* (Fig. 203), of a darkened room, the pencil of light L, falling through that hole, will produce a round spot of white light on the floor, *c*. If a prism of glass, *e*, is now interposed in the path of the ray, it is refracted by the glass, and not merely does it suffer a change of direction, but, instead of exhibiting a white spot, it now presents an elongated, flame-like, beautifully coloured image, *f g*; the ordinary colours being *red*, *orange*, *yellow*, *green*, *blue*, *indigo*, and *violet*. This chromatic image is called the *Newtonian spectrum*, the *solar spectrum*, or the *prismatic spectrum*. Sir Isaac Newton

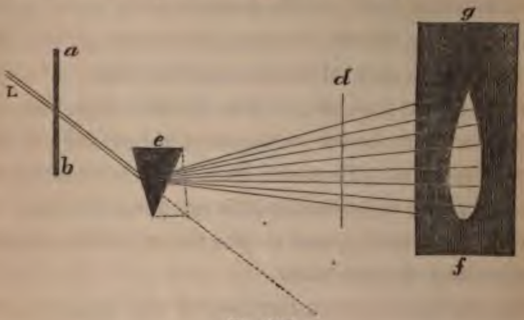


Fig. 203.

measured the length of each of these rays; they have since been measured with great care by Fraunhofer: their results are as follows:—

	Newton.	Fraunhofer.
Red	45	56
Orange	27	27
Yellow	40	27
Green	60	46
Blue	60	48
Indigo	48	47
Violet	80	109
Total length	360	360

The discrepancies in these measurements depend upon the fact that the eyes of no two individuals are equally sensible to all the coloured rays. I have repeatedly made my friends prick with a needle the point which they each considered would mark the extremity of one of the rays: it was very rarely that I found any two individuals who would indicate the same line.

From these results Sir Isaac Newton considered that white light was a compound of seven primary rays; and he was confirmed in this opinion, from finding that the coloured rays were not again susceptible of change by refraction. Hence he called those rays *homogeneous*, or simple light, and white light *heterogeneous*, or compound. These seven colours he called the *primary colours*, and any combinations of these primaries he called *secondary colours*. These rays may be recomposed into white light. If we place a second prism against the first, the ray will be slightly bent, but it will remain white light; therefore the coloured rays are due, not to the refraction of the glass merely, but to the different thicknesses of the triangular body employed.

If we take a piece of paper and divide it into sectors, of the sizes indicated for each of the rays, and then cause it to revolve very rapidly, they blend, neither of them being enabled to make a stronger impression on the retina than another. It has been stated that white light is the result; but if a spot of white paper is left on the disc, it will be seen that the colour resulting from rotation always falls far short of whiteness. It does not appear that this depends, as is commonly stated, on the impurity of the colours employed, since by no combination of pigments of these primary colours can anything but a deep neutral tint be produced. It is very common in books of science, to find it stated that by mixing powders of the colours of the rays of light a grey approaching to white is produced; this is an error, which has been again and again repeated, evidently without examination. A neutral lavender may be formed, but the usual result is a deep brown, —with some colours an absolute black,—but never any advance towards whiteness.

Light may be decomposed by *absorption*, as is the case with coloured glasses or fluids. In these examples, the ray which passes through the coloured medium is not the pure ray, but a mixture of all the rays which are not absorbed; at least this is the received idea, and it is rare, if we analyse the ray which has permeated a red or blue glass, to find it either a pure red or a pure blue.

Sir David Brewster instituted a very searching examination of the conditions of the spectrum; and as the evidence obtained is of a very important character, it cannot be given in other language than his own. After describing that if an observer looks at a hole in the window-shutter of a darkened room, through a prism, he will see the spectrum, he proceeds:—

"Let the blue glass be now interposed between the eye and the prism, and a remarkable spectrum will be seen, deficient in a certain number of its differently coloured rays. A particular thickness absorbs the middle of the red space, the whole of the orange, a great part of the green, a considerable part of the blue, a little of the indigo, and a very little of the violet. The yellow space, which has not been much absorbed, has *increased in breadth.* It occupies part of the space formerly occupied by the *orange* on one side, and part of the space formerly covered by the *green* on the other. Hence it follows, that the blue glass has absorbed the red light, which, when mixed with the yellow light, constituted orange, and has absorbed also the blue light, which, when mixed with the yellow, constituted the part of the *green* space next the *yellow*. We have, therefore, by absorption, decomposed *green* light into *yellow* and *blue*, and *orange* light into *yellow* and *red*; and it consequently follows, that the orange and green rays of the spectrum, though they cannot be decomposed by prismatic refraction, can be decomposed by absorption, and actually consist of two different colours, possessing the same degree of refrangibility. *Difference of colour is, therefore, not a test of difference of refrangibility*; the conclusion deduced by Newton is no longer admissible as a general truth—'that to the same degree of refrangibility ever belongs the same colour, and to the same colour ever belongs the same degree of refrangibility.'

"With the view of obtaining a complete analysis of the spectrum, I have examined the spectra produced by various bodies, and the changes which they undergo by absorption when viewed through various coloured media, and I find that the colour of every part of the spectrum may be changed, not only in intensity, but in colour, by the action of particular media; and from these observations, which it would be out of place here to detail, I conclude that the solar spectrum consists of three spectra of equal length, viz., a *red* spectrum, a *yellow* spectrum, and a *blue* spectrum. The *primary red* spectrum has its maximum of intensity about the middle of the *red* space in the solar spectrum, the *primary yellow* spectrum has its maximum in the middle of the yellow space, and the primary *blue* spectrum has its maximum between the blue and the indigo space. The two minima of each of the three primary spectra coincide at the two extremities of the solar spectrum.

"From this view of the constitution of the solar spectrum we may draw the following conclusions:—

"1st. *Red*, *yellow*, and *blue* light exist at every point of the solar spectrum.

"2nd. As a certain portion of red, yellow, and blue constitute *white* light, the colour of every point of the spectrum may be considered as consisting of the predominating colour at any point mixed with white light. In the red space there is more red than is necessary to make white light with the small portions of yellow and blue which exist there; in the yellow space there is more yellow than is necessary to make white light with the red and blue; and in the part of the blue space which appears violet, there is more red than yellow, and hence the excess of red forms a violet with the blue.

"3rd. By absorbing the excess of any colour at any point of the spectrum above what is necessary to form white light, we may actually cause white light to appear at that point, and this white light will possess the remarkable property of remaining white after any number of refractions, and of being decomposable only by absorption. Such a white light I have succeeded in developing in different parts of the spectrum. These views harmonize in a remarkable manner with the hypothesis of three colours, which has been adopted by many philosophers, and which others had rejected, from its incompatibility with the phenomena of the spectrum."

Sir David Brewster, therefore, supposes the coloured band of light to be the result of the overlapping of three coloured spectra of the same lengths—a red, a yellow, and a blue spectrum. Difficulties are, however, to be named which neither the theory of Sir Isaac Newton nor the views of Sir David Brewster will in all respects explain.

If we look at a prismatic spectrum through a cobalt-blue glass, the eye, being screened from the glare of the yellow ray, becomes sensible of a rich *crimson ray*, below the ordinary red, which Sir John Herschel has called the *extreme red ray*; and if the spectrum is received upon a paper stained yellow by turmeric, a new ray makes its appearance beyond the *violet ray*, the discovery of which is due to Sir John Herschel, and this is of a neutral tint—*a lavender ray*. Thus we have increased the bands of the spectrum from seven to nine, as is shown in the central coloured image of the Frontispiece.

Sir David Brewster's explanation holds for all the rays from the ordinary *red* to the end of the *indigo*; but it does not fully explain the *increase of illuminating power* which is evidently shown in the *violet* ray, the appearance of the *lavender* ray, and scarcely the reappearance of *blue blending* with the *red* to produce the beautiful crimson ray at the least refrangible end.

The luminous intensity of the rays has been given numerically as follows:—

Extreme Red ray	32
Red ray	94
Yellow	1000
Orange	640
Green	480
Blue	170
Indigo	31
Violet	6

From a most attentive examination of the subject,—and this, too, under almost every condition of experiment which could present itself to my mind,—I have a strong conviction that, as far as the violet ray is concerned, there is an error, and that its illuminating power is greater than that of the indigo ray. I am disposed to explain the condition of the prismatic colours under an impression that we have the compound spectrum of three colours repeated in all our experiments,—that we have conditions similar to those with which we are familiar in the phenomena of the rainbow, *i. e.* the appearance of the supplementary bow,—that we have the ordinary spectrum, and an *extraordinary* spectrum with the order of its colours inverted. This being assumed, we should have the conditions shown by the tinted portions of the coloured diagram of the Frontispiece. We have on one side the least refrangible end, the *yellow* ray, blending with the red to produce the *orange*, then the *pure red*, terminating the ordinary spectrum, the *crimson* ray being produced by the red of the *ordinary*, receiving some illumination from the blue of the *extraordinary* spectrum. On the other side, the most refrangible end, we have the yellow blending with the blue to produce the *green ray*, then the *pure blue*, which, passing into blackness, gives rise to the *indigo ray*; the space beyond this receives some additional illumination from the red of *the extraordinary spectrum*, and the result is the *violet* ray, and the *lavender*, under the conditions of reflection from a yellow ground.

The vignette at the head of this chapter shows the rainbow and its supplementary bow. The formation of the rainbow may be explained thus. A ray of light falling upon a drop of rain becomes refracted on entering the first surface, it is reflected from the other surface of this sphere, and thus, emerging from a medium point, suffers prismatic refraction; the least refrangible rays, the red, forming the inner portion of the bow, the most refrangible, the violet, its outer edge. The supplementary bow is due to a double refraction and reflection of the sun's rays.

The theory of Goethe has not received the attention it merits, notwithstanding the translation by Eastlake of the German poet-philosopher's 'Theory of Colours.' His hypothesis may be briefly stated to be, that light is pure and homogeneous; that, robbed by reflection, absorption, or refraction, of one degree of its intensity, we have *yellow* light; *deprived of* another, that we have red illumination; and that, reduced to its lowest degree of visible intensity, we have a *blue*, which passes into black, or the absence of light. Goethe illustrates his views in this way :—place over a slit in the window-shutter of a darkened room, one piece of parchment, we have yellow light transmitted; put two, and the light becomes red; place three or four thicknesses over the opening, and the light is then blue.

Before quitting the subject of prismatic refraction, it is necessary to state that both Wollaston and Fraunhofer have shown that the solar spectrum is not continuous, but that there are numerous interruptions to the continuity of the rays in the shape of dark lines. These are usually called *Fraunhofer's dark lines*,—that celebrated optical observer having detected more than five hundred of these lines in the spectrum. The best mode of observing them is to receive the spectrum upon a screen in a dark box, the spectrum being rendered more intense by employing a lens to concentrate the rays previously to their falling on the edge of the prism, which should be of the utmost purity. This image should then be observed by means of a small telescope. According to the undulatory theory, these dark lines are supposed to be produced by the depressions in the wave of the luminous ether.

Dissimilar bodies produce spectra whose lengths are different, owing to the differences in the properties of the substances in relation to the *dispersion of light*. Flint glass is said to have a greater dispersive power than crown glass, because at the same angle it separates the two extreme rays farther from the mean luminous ray. Attention to the law of the dispersion of light is most important in optics; and on a knowledge of the dispersive powers of glasses depends the construction of achromatic lenses. When rays of white light pass through a lens, as is already stated, they suffer spherical aberration; and, from the prismatic character of lenses (Fig. 204), objects viewed through them and images formed by them are coloured at their edges, from the decomposition of the light. This is called *chromatic aberration.* These fringes of colour are exceedingly objectionable in astronomical telescopes, and it became important to discover some means by which this aberration might be counteracted. Dollond, observing that the prismatic dispersion in English flint glass is $1\frac{1}{2}$ times as great as in crown glass, was the first to suggest, that, by combining two such bodies, the chromatic dispersion would be corrected. Newton thought this was impossible, but Dollond, in 1757, was successful in producing lenses and prisms of perfect achromaticity. Supposing one of the lenses in Fig. 204 to be of crown and the other of flint glass, it will be obvious, when two such glasses are combined, that the rays refracted by one prismatic medium will be restored to their original line by the other; and hence *achromatic lenses* of great power and

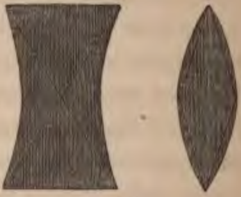


Fig. 204.

considerable perfection are now made of combinations of English crown and flint glass.

The colours of natural objects depend upon some peculiar function of the surfaces of non-transparent media, to send back to the eye light of a peculiar colour, and, in transparent bodies, to the power of the medium in relation to molecular structure, to allow the permeation of certain rays.

Sir Isaac Newton's theory was the first approach to a correct understanding of the phenomena, but his views have not stood the test of the examination of modern science. That the colours of all bodies are due to the power of the body to act upon light is proved; colour is not a quality inherent in the body. A red body appears red because it reflects red light back to the eye; a yellow one looks yellow because yellow light is more powerfully thrown back from its surface; and so on, through all the colours. We have artificial means by which we can produce luminous effects which have only one colour. Thus, by burning nitrate of strontian, a monochromatic light of a pure red is produced; by nitrate of barytes a green light is occasioned; and by driving a jet of burning gas through a collar of salt an intense yellow illumination results. If a red body is placed in a red light its colour is exalted, but a yellow wafer in such a light would appear red, because none other than red rays can be reflected from its surface. A red body placed in yellow light loses all its redness, and so on, for every other coloured body and monochromatic light.

The views of Newton demand some attention, and they may be briefly stated as follows:—

The superficies of bodies having the greatest refracting power, reflect the greatest quantity of light.

The least parts—the smallest divisions—of all natural bodies are partially transparent, and the opacity of such bodies arises from the multitude of reflections caused in their internal parts.

All bodies have void spaces, and on the number and distribution of these depends transparency or opacity.

"The transparent parts of bodies reflect rays of one colour, and transmit those of another, on the same grounds that thin plates or bubbles do reflect or transmit these rays, *and this I take to be the ground of all their colours.*"

The parts of bodies on which their colours depend are denser than the medium which pervades their interstices.

The bigness of the component parts of natural bodies may be conjectured by their colours.

According to the undulatory theory of light, the colour of natural objects is the result of the power which they possess of altering the undulation of the luminiferous ether. White light, the result of a wave of a certain length, falls on a surface, and it is thrown back with some alteration in its rate of movement, or length of wave, and thus colour is the result. The following table represents the conditions, as obtained by Newton's calculation, necessary for the *production* of colour:—

Colour of Rays.	Length of luminous waves in an inch.	No. of undulations in an inch.	No. of undulations in a second. Millions of millions.
Red	0·0000266	39,180	477
Orange	0·0000240	41,610	506
Yellow	0·0000227	44,000	535
Green	0·0000211	47,460	577
Blue	0·0000196	51,110	622
Indigo	0·0000185	54,070	658
Violet	0·0000174	57,490	699

Violet light is, therefore, according to both the theories, due to nearly twice as many undulations as those necessary to produce red light; and a similar difference exists in the number of vibrations required in a second of time. The Newtonian and undulatory theories of colour thus meet, as determining the production of the phenomena.

That colour is due to molecular arrangement is shown by a few conclusive experiments. The biniodide of mercury is a beautiful scarlet salt; if a little is placed on a piece of glass and made hot, it becomes yellow, and it remains so if undisturbed; but the slightest touch with any hard body occasions it to return rapidly to its original red colour. Chameleon mineral is a solid substance produced by fusing peroxide of manganese with potash, thus producing a permanganate of potash: when dissolved in water it changes, according to the amount of dilution, from green to blue and purple. When indigo, spread on paper, is exposed to heat, it becomes red; and the yellow sphate of lead turns green with the application of heat.

Some bodies have the power of reflecting from their surfaces one colour whilst they transmit another. This is the case with the precious opal. A solution of sulphate of quinine in water acidulated with sulphuric acid, is colourless and transparent to the eye looking through it; but looking at it, it appears intensely blue. An oil obtained by the distillation of resin transmits yellow light, and reflects violet light. These dichroic phenomena, or double colour of bodies, have been studied by Sir John Herschel, and referred by him to the action of the most superficial film of the fluid; and hence termed *epipolic*, or surface action. Other bodies exhibit similar effects. The blue of the atmosphere is reflected light, but its red tinge is a consequence of transmitted light. Smoke reflects blue light, but transmits red; chromate of alum is green in reflected light, but purple in the transmitted rays.

The production of colour under a few other conditions must be named. If a lens is placed on a flat piece of glass it touches it only at one point, around which we have a very attenuated film of air; and such a film gives rise to series of beautifully coloured rings (Fig. 205), consisting of a number of spectra varying in the order of their colours. These very beautiful rings are sometimes shown with the most striking effect in rock crystal, and even in masses of glass where there are slight *fractures*, giving rise to very thin plates of

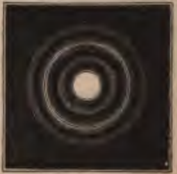


Fig. 205.

air. The varying play of colours on a soap-bubble, and those of films of oil on water, are due to the same cause. By a little arrangement called the iriscope, the colours of a soap-bubble may be easily studied. A solution of soap being made, is put into a phial while still boiling hot; the heat and escaping vapour expel much air; the bottle is corked, and thus, when cold, there is an attenuated atmosphere produced in the vessel. By placing the bottle on its side, and giving it a gentle shake, a film is produced. After it has grown thin by standing, we shall see a great many concentric coloured rings, and as the film grows thinner the rings will dilate; the centre will pass from white to blue and black, while the rings present a curious order of change. Newton has proved that these rings are produced by films varying in thickness from $\frac{1}{178000}$ to $\frac{8}{178000}$ of an inch. The colours of thick films were also investigated by Newton, and more recently by Herschel and Brewster, to whose works the reader is referred.

The colours of fibres, and of grooved surfaces, are easily seen. If we dust some hair-powder or lycopodium upon a glass plate, and look through it at a candle, it will appear surrounded by a halo. Fibres of silk or wool spread out closely together, give rise to similar coloured rings. The colours of mother-of-pearl are due to the infinite number of fine grooves upon its surface; and if we copy them on white wax, this substance gives the same iridescent phenomena. By drawing a series of exceedingly fine lines on steel, or any other metal, we may in the same way produce iridescent phenomena, and the iris ornaments are obtained by cutting on the surface of the steel a great number of fine lines. In all these cases, colour would appear to be produced by the refraction of the ray. Results somewhat similar are produced by diffraction. Pass nto a dark room a ray of light, receive it on a glass rod blackened, and look at it through a slit in a card: the appearance shown in Fig. 206 will be obtained; a line of bright light occupying the centre of the whole, and on either side spectra separated from each other by dark bands.

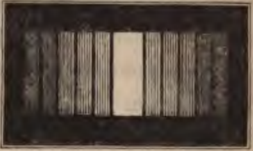


Fig. 206.

Looking at a candle through the divisions of a fine feather, we obtain a very beautiful exhibition of the phenomenon of diffraction, which appears to be of the same character as that of interference.

A very beautiful and splendid class of phenomena has been investigated and described by M. Fraunhofer, which are produced by such a regular arrangement of circles and squares, as would be formed by two equal wire gratings crossed at right angles. The lower central figure of the Frontispiece represents the effect when the light is received on the object-glass of the telescope, through two circular holes. Each compartment is a separate spectrum of great beauty. The appearances vary as the number of apertures is increased, the spectra growing more vivid. These results are due to the diffracted fringes produced by the decomposition of the light in passing the very fine orifices of the crossed wires, or of circular holes in metal plates.

The phenomena of *interference*, as it is called, afford very strong support to the undulatory theory. An experiment by Dr. Young explains the result in the most intelligible manner. He admitted a sunbeam through a hole made with a fine needle in thick paper, and brought into the diverging beam a slip of card one-thirtieth of an inch in breadth, and observed its shadow on a white screen at different distances. The shadow was divided by light and dark bands alternately arranged, but the *central line* was always white. In the same manner, if we place a small solid opake sphere in the diverging ray, a white spot of light will appear in the centre of its shadow.

This would appear to indicate that light can turn a corner,—that the rays are susceptible of bending out of the parallel lines in which light is supposed to progress. This is conjectured, by the advocates of the undulatory theory, to be merely the effect of the depression of the ethereal wave; but a much more natural explanation is afforded by those experiments which prove that solid surfaces have the power of condensing, with more or less force, all attenuated forms of matter upon them, and around their edges.

In support of this idea of wave motion, the production of darkness by the blending of two points of light is brought strongly forward. The familiar mode of explaining this is the following.—Standing at the confluence of two rivers, it will be observed, that when the waves from each meet in the same state of vibration, the resulting wave will be equal to the two combined; if, however, one wave is half an undulation behind the other, the crest of one will meet the hollow of the other, and comparatively smooth water will be the result.

If two pencils of light radiate from two points very close to each other, and this light falls upon the same spot of a piece of paper held parallel to the line joining the points which bisect the distance between the two radiant points, they may be said to *interfere*; they cross each other at one point, and this is called the point of interference. If the waves move at the same rate—or rather, if the two waves reach the point of interference at the same degree of elevation—a spot of double the luminous intensity of either ray separated is produced; but if one is half a vibration behind the other, the result will be that a dark instead of a light spot will be apparent. The explanation afforded by the theory of undulations is quite complete for all these phenomena; but the Newtonian hypothesis of "fits of easy transmission and easy reflection" evidently supposes a similar condition of progress.

We have already considered the question of ordinary refraction; extraordinary or double refraction must now be noticed. If any transparent substance has an unequal constitution, or if we can produce an inequality of elasticity by mechanical pressure or by heat, the ray falling on its surface undergoes two refractions; that is, the single pencil is divided into two pencils in passing through the medium. *Iceland spar* is a remarkable example of a body possessing naturally unequal densities; and if we transmit a ray of light through it, one part will be refracted according to the ordinary laws of refraction, and is called the *ordinary ray*; the other part will be refracted according to some extraordinary law, and is called the *extraordinary ray*. That this is due to the molecular structure of the medium through which the light passes, is proved by taking a cube of regularly annealed glass; it produces but one refracted pencil; subject it to the pressure of a screw, or heat it unequally, a change is produced in the arrangement of its parts, and double refraction takes place. The rays are not in this case separated into two distinct pencils, but the decomposition of the ray is effected, and we produce colour by the interference of the waves. Double refraction may under some circumstances produce colour, and colour may be a test of double refraction, when the rays are not sufficiently separated to form two distinct images.

The celebrated Huyghens was the discoverer of the law of double refraction, a complete elucidation of which requires high mathematical knowledge and much experimental skill. The phenomena involve so many abstruse investigations, and require so large an amount of preliminary education in a particular direction, that it is impossible to enter satisfactorily on the subject in a work so entirely elementary as the present one is intended to be.

The polarization of light—implying, as it does, some connection with a polar arrangement of particles—is an exceedingly unfortunate name for a most remarkable class of phenomena. In 1808, Malus, a young engineer officer, was viewing, through a double-refracting prism, the light of the sun reflected from a glass window of one of the French palaces, and he observed some peculiar effects. The window accidentally stood open, like a door on its hinges, at an angle of 55°, and it is found that a ray of light reflected at an angle of 56° 45′ is altered in its character,—it is polarized.

A ray of light, *a*, falls on a mirror, *f g h i*, which is adjusted to the proper angle of polarization; the ray reflected from it, *b c*, falls upon the reflecting mirror, and is reflected in the direction *c d*; the incident, *a b*, the polarized, *b c*, and the reflected rays, *c d*, being in one and the same plane. If we allow the pencil of light to fall upon a plate of glass at any usual angle of incidence, one portion of light will be transmitted and one will be reflected; and if we place a second plate of glass over the reflected ray, a second reflection will take place on whatever side of the ray the reflecting glass may be placed. But if the ray is incident upon the second glass at an angle of 56° 45′ from the perpendicular, the light reflected by the first glass will be again reflected by the second when the planes of the two glasses are parallel to each other; but if,

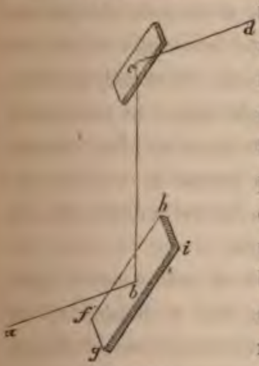


Fig. 207.

without altering its angle to the horizon, we turn the second glass the quarter of a circle, the light will be transmitted, not reflected; if we turn it another quarter, the light will be reflected, not transmitted. By this we prove that light reflected at an angle of incidence of 56° 45′ has undergone some peculiar modification.

A stretched string may be employed to familiarize the probable conditions of polarized light. If we move the string slowly up and down, we produce a series of waves from the hand towards the fixed point, like the waves of the sea, or those which pass over a field of standing corn. Now, if at the same time as we make this up and down movement, we pass the hand from right to left with tolerable rapidity, we send two sets of vibrations along the string at the same time at right angles to each other. The direct wave would appear to represent the ordinary ray; we turn the beam round a quarter of a circle, and we then see the effects of the lateral vibrations,—we become conscious of polarized light.

Supposing we imagine a section of such a ray of light, it would appear that something like a division of the section takes place: the perpendicular portion of the ray is transmitted, the horizontal vibrations reflected.

The annexed woodcut (Fig. 208) represents one of the most useful forms of polarizing apparatus; it is called a *polariscope,* and by its adjustments the measurement of the angle of polarization is easy, and many remarkable phenomena can be examined. The frame A B encloses a polished glass, and it may be made to revolve in a horizontal apex by means of a pivot. This mirror is usually placed in such a position that its plane makes an angle with the vertical of 35°. A ray of light, *a*, falls on it, and passes partly through the glass, and is partially reflected downward to *c*, as a polarized ray, where there is a blackened mirror which reflects the ray back through the polarizing mirror A B, to the mirror at the top of the stand. The graduated adjustments and movements enable the observer to place the mirrors at various angles, and to observe all the phenomena of polarization, and also to place any transparent object in the line of the ray, and observe the numerous beautiful effects of polarization.

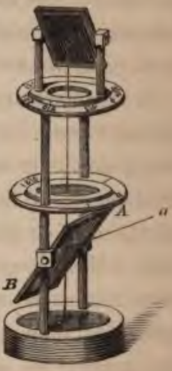


Fig. 208.

There are three kinds of polarization. *Plane polarization* may be produced by reflection at an angle between 53° and 68° from the surface of any bodies not metallic; the law discovered by Sir David Brewster is, that "*the index of refraction is the tangent of the angle of polarization.*" Plane polarization may also be produced by the refraction of light,—by several refracting surfaces acting upon the ray in succession. The number of plates of glass required to polarize the whole beam depends upon its intensity and the angle at which it is incident. At an angle of

41° 41′ the light of a wax-candle is wholly polarized by forty-seven plates of glass, and at an angle of 79° 11′ it is polarized by eight plates. Plane polarization is also produced by the double refraction of crystals: each of the two pencils is polarized, like light reflected from glass, at an angle of 56° 45′, but in opposite planes.

The chromatic phenomena of polarized light are of exceeding beauty. If polarized light be transmitted through thin slices of crystallized bodies, which have been cut in the direction of their primary axis of crystallization, the light, on being polarized a second time, displays some remarkable changes. Sir David Brewster remarks, after describing some of these experiments made with Iceland spar—"It does not appear, from the preceding experiments, that the polarization of the two pencils is the effect of any polarizing force resident in the Iceland spar, or of any change produced upon the light. The Iceland spar has merely separated the common light into its two elements, according to a different law, in the same manner as a prism separates all the seven colours of the compound white beam by its power of refracting those elementary colours in different degrees. The re-union of the two oppositely polarized pencils produces common light, in the same manner as the re-union of all the seven colours produces white light."

If we place upon the stand of the polariscope a thin film of sulphate of lime or mica, so that the polarized ray passes through it, we shall see its surface covered with the most beautiful colours; and by turning the plate we make them dissolve, and re-appear with a change in their order, in a manner which is very striking. Coloured rings are formed about both the axes of such crystals as have two axes, these being intersected by the form of a cross, as shown on the upper figures of the Frontispiece. Those on the lower part represent the figures formed by placing two uniaxial crystalline plates across each other, and in the polarizing apparatus turning them round their own plane. The black or white cross is then faithfully and uniformly delineated, and the complementary bands produced at will.

Circular polarization is produced by light when it is twice totally reflected from the second surfaces of bodies at their angle of maximum polarization. It may be produced by rock crystal, and, as discovered by Seebeck and Biot, in passing through certain fluids. It has, indeed, become a means of the most delicate analytical research; the adulteration of any fluid body being at once detected by the alteration of its order of polarization.

Elliptical polarization is produced by reflections at angles between 70° 45′ and 78° 30′, from the polished surfaces of metals; tin having the greatest, and gold the least, polarizing angle. The discovery of this is due to Sir David Brewster, to whom this branch of optical science is under many obligations. Further information on this very complicated subject must be sought for in the works *of Herschel*, Brewster, Biot, Pouillet, and Arago.

ACTINISM.—The chemical agency of the sun's rays has received this name, which signifies nothing more than *ray power*; and its operations are manifested in many very striking results. If, upon a piece of paper covered with chloride of silver, the prismatic spectrum is thrown, it will, in a short period, mark out the curious image shown on the left-hand of the Frontispiece. Upon examining it, we shall find that where the most *light* fell upon the paper—*i. e.* the yellow ray—no chemical change takes place; the paper begins to darken within the limits of the green ray, and the chemical change proceeds with the utmost intensity through the blue and violet. Beyond the spectrum, where there is no light, the chemical change is to be traced over a considerable space. The red ray, upon some preparations, produces a decided chemical change; but over the space marked by the extreme red ray (the maximum heat-point) no chemical change is effected.

By the use of absorbent media we are enabled to separate the luminous and the chemical principles of the sun's rays from each other. If we take a very dark cobalt-blue glass, we shall find that, although it will obstruct a considerable amount of light, it does not in any way prevent the free permeation of the chemical rays; paper spread with any sensitive preparation, or a Daguerreotype plate, is as rapidly affected as if no such screen had been interposed. On the contrary, if we take a pale yellow glass stained with oxide of silver, and place the most sensitive photographic preparation behind such a medium (or we may employ water stained yellow with the bichromate of potash), we shall discover that although no *light* is interrupted, all chemical change is prevented. Not only does the luminous power of the sunbeam not produce chemical change, but it protects from the disturbing force of Actinism.

This is shown by the following experiment (Fig. 209):—L, a sunbeam, falls, after passing through a small hole in a window-shutter, *a b*, on a prism, *e*; and the refracted ray, after passing through a screen of pale yellow glass, *d*, falls upon paper spread with the most highly sensitive photographic material, *g f*. In all cases there is a sufficient quantity of diffused light to act slightly on such sensitive preparation, consequently the paper darkens slightly over every part except that upon which the brilliantly luminous spectrum falls. The yellow glass makes

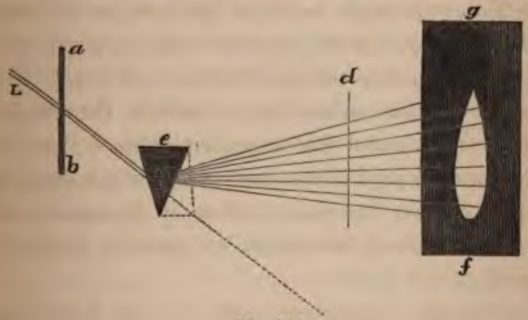


Fig. 209.

but slight alteration in the colours of the prismatic image, and none whatever in its illuminating power; but it has obstructed the chemical principle, and the luminous rays protect the paper from change. If the sunshine is reflected from a mirror upon the paper, without at all disturbing the previous arrangement, it will be found that every part will blacken except that portion on which the luminous rays fall.

It is thus distinctly proved that the solar beam consists of three principles:—LIGHT, *luminous power*, which produces the phenomena of colour, and is the external cause of vision; HEAT, *calorific power*, the principle which determines, by its antagonism to cohesion, the physical forms of matter; and ACTINISM, *the chemical principle*, upon which depend all the chemical changes involved in the photographic processes and all the important chemical processes in the vegetable world, and probably also in the other kingdoms of nature.

Photography—*light-drawing*, as it is most unfortunately called, since light, it is shown, opposes the chemical change upon which the production of these pictures depends,—consists in preparing a silver plate by exposing it to the influence of iodine, or in spreading upon paper either the chloride, iodide, or bromide of silver, and exciting these to the point near which change would take place in the dark, by a wash of either the protosulphate of iron or of gallic acid. It is then placed in the camera obscura, that instrument being previously adjusted for the image of some external object to fall upon the plate or paper when it is slid into its place. Relatively, the quantity of light and of actinism reflected from any object are the same; therefore, as the light and shadows of the luminous image vary, so will the power of producing change upon the paper vary also; and the result will be the production of an image which will be a faithful copy of nature with reversed lights and shadows. The lights darken the paper, while it is preserved white in the shadows; this is called *the negative image.*

If the picture is to be obtained on a silver plate—the process of Daguerre—the image is not allowed to develope itself in the camera; but is evoked by the agency of mercurial vapour. There are some remarkable physical phenomena connected with the bringing out of the dormant image, which deserve attention. The iodized silver plate is taken from the camera without there being any trace of an image, even when examined by the highest magnifying power: but the vapour of mercury, condensing on the plate, arranges itself in the most uniform manner, each layer of mercurial vapour being, relatively to every other one, according to its thickness an exact measure of the quantity of solar action. Where the shadows are deep, there is scarcely a trace of mercury; and where the lights are strong the metallic dust is deposited of considerable thickness. Certain forces residing on the surface of bodies—epipolic forces—have been already named; what *may be the true* nature of these we know not, but it appears that under the agency of the solar radiations they are either exalted or depressed, and to this, it is considered that the deposition of the mercury on the Daguerreotype plate is due. The development of the picture in the calotype process of Mr. Talbot, and in the exceedingly sensitive Ferrotype of the author, is due to the action of gallic acid in the first, and of the protosulphate of iron in the last; the change—de-oxidation—being determined by the momentary influence of actinism. Draper first showed that a substance exposed to sunshine assumed a condition different from that which it had if preserved in darkness. He found that chlorine exposed to sunshine acquired the power of uniting with hydrogen, under circumstances where chlorine prepared in the dark would not enter into combination with that gas. The author subsequently discovered that a solution of the protosulphate of iron exposed to sunshine would precipitate gold or silver from their solutions much more rapidly than such as had been preserved in darkness; and, indeed, that the solutions of silver and gold appeared to acquire a new condition by a similar exposure, being more readily acted upon by any decomposing agent than such solutions as had been kept in the dark. It might be inferred from this, that something had actually been absorbed by the solutions, particularly as this new condition is retained for some time by the solutions; but I imagine that the results are to be explained by a mere change of condition. That such changes may be produced is strikingly proved by the formation of an allotropic phosphorus. If this waxy-looking and highly combustible body is sealed up in a glass tube, and subjected to the influence of the solar spectrum, that portion which is exposed to the action of the least refrangible rays becomes red and granular, and it will be found, upon examination, to have lost much of its combustible character; that portion acted on by the most refrangible rays undergoing no such change.

We may therefore understand how, before any actual chemical change has taken place in the sensitive surface of the photographic tablet, that a physical alteration may be set up, thus determining towards a chemical change; and any proper agent employed, turns the balance of action immediately in that direction.

The *Heliographic* process of Niepce consisted in exposing a surface covered with resin to the solar rays:—that portion on which the bright light fell became much more soluble than those parts which had been influenced by the weaker rays, and could consequently be dissolved off before the other portion. In this case I apprehend a physical change alone is effected.

This is not the proper place for describing any of the photographic processes; but it may be correct to mention that Sir John Herschel has employed gold, iron, mercury, and vegetable juices, as photographic agents; that the author has found that platinum, nickel, cobalt, manganese, and a great variety of other bodies are influenced by the sun's rays. Beyond this, it has been demonstrated that the pure polished surfaces of nearly all the metals, of glass, of marble and slate, and even the surfaces of wood, are susceptible of molecular disturbance under the influence of sunshine. The truth of an assertion made by Niepce is fully confirmed. During daylight every body, both organic and inorganic, is undergoing a change; and it has been as satisfactorily shown, that during the hours of darkness all matter has the power of restoring itself to the condition in which it was previously to the *destructive action* of the sunshine; therefore, night and rest are necessary to the permanence of the solid earth.

Dr. Wollaston was the first to prove that the rays at one end of the spectrum had the power of undoing what the rays at the other had effected. By exposing to sunshine a paper washed over with an alcoholic solution of gum guaiacum, he found—that it lost its yellow-brown colour and became green,—that this was due to the most chemically active rays, and that the original colour was restored by the action of the least refrangible radiations. That this is due to thermic action is evident from the circumstance that artificial heat produces the same effect.

This dual influence of the spectrum has been observed in a great variety of instances. When papers, covered with oxide of silver and washed with an iodine salt, are exposed to the influence of the spectrum; over all the space covered by the blue, indigo, and violet rays, and by the invisible rays beyond the luminous image, it is *bleached*; but over the space covered by the red rays it is blackened.

The influences exerted by the solar rays on electrical phenomena are sufficiently curious, and, as far as they go, instructive; although these have not been sufficiently examined to enable us to determine any law of action.

In a galvanic arrangement, it has been found that when the violet rays are thrown upon the positive plate the action is increased, and that when the yellow or red rays are projected on it there is no influence. Edmond Becquerel, by employing screens of variously coloured glass, obtained the following results:—

Colour of screens.	Intensity of current.	Relative effects.
No screen	35·5	100
Violet	9	27
Blue	10·5	31
Green	1	2·5
Yellow	6·5	10·5
Red	1	2·5

These glasses had not, however, been previously examined; we know not the rays which actually passed through them; therefore we only obtain, as a general result, the indication that the chemical end of the spectrum produced the greatest electro-chemical action. The results, however, which have been obtained, and which have been briefly described, go towards establishing the fact of the existence of three physical principles in the solar radiations, namely,

LIGHT.—*Luminous power*, producing the phenomena of vision and all the effects of colour.

HEAT.—*Calorific power*.

ACTINISM.—*Chemical power*, distinguished from the other two by its being non-luminous, and possessing no thermic action.

These are associated in operation, being balanced against each other in the sunbeam in such a beautifully harmonious order, that the influences of each are modified.

The operations of these forces or principles on the organic world are remarkable. These are best exemplified by the influences which we detect when the radiations are made to act, as perfectly isolated as possible, upon plants in the various stages of their growth. The following quotations from the author's report on this subject to the British Association, will place this question in the most satisfactory point of view.

"Without entering into any discussion in this place on the probable existence, or otherwise, of a principle distinct from light and heat in the sun's rays, to which to refer the curious chemical changes produced by solar influence, it will be sufficient to admit the existence of three distinct classes of phenomena, which cannot, I think, be disputed.

"These are—luminous influence, calorific power, and chemical excitation.

"The problem which these researches were directed to solve, was the proportion and kind of influence exerted by light, heat, and actinism, in the various stages of vegetable growth.

"The means we have of separating these phenomena from each other are not very perfect; indeed, in the present state of our knowledge, it is impossible to have evidence of the operations of either light, heat, or actinism absolutely separated from each other. If we use the prismatic spectrum, we have over every portion of it a mixture of effects. Even in the mean yellow, or most luminous ray, we have a considerable amount of thermic action, and, under some circumstances, evidence of chemical power. In the violet rays, which have been particularly distinguished as chemical rays, we have light and heat; in the calorific rays, we have decided proof of both luminous and actinic power. In the experiments which have been made with the prismatic spectrum, we have in fact no certainty that the results stated to be due to a particular ray—that ray being regarded as the representative of a particular phenomenon—are not the combined effect of the three forces.

"The same objections apply to absorbent media, but the amount of each influence is readily determined; and we are therefore enabled to refer any particular result to a tolerably well-defined agency.

"All the experiments recorded in this report have been made under the action of those radiations which have permeated variously coloured media, such as tinted glass and coloured transparent fluids. It is not sufficient to state that a yellow, red, or blue glass or fluid was employed, as it by no means follows that these media are permeated only by the rays corresponding in colour, or by the influences due to a given order of refrangibility.

"The amount of light has been determined by measuring off the prismatic rays which pass the screen. This is preferable to any system of measuring which depends upon the power of the eye to appreciate either light or shadow. Having formed a well-defined spectrum on a white tablet, and carefully marked off the centre of the yellow ray as being the point of maximum light, and the limits of each of the other rays, the transparent coloured medium was interposed and the amount of absorption observed. These examinations, many times repeated, were made with reference to the luminous rays only; and in the description of my experiments, I shall, considering the unabsorbed ray as being represented by 100, express the amount of light actually effective by such a number as may give the sum of the rays measured off after permeation.

"The calorific influences which escape absorption, and which have been determined by the expansion of the mercury in a thermometer with a blackened bulb placed behind the coloured glass or fluid, and by the evaporation of ether from a sheet of blackened paper, as recommended by Sir John Herschel, will be expressed numerically in the same way as light, without reference to the colour of any ray. I am far from considering the thermic influences of the solar rays as quite independent of the colour of the ray with which they may be associated, but in these experiments on plants, it appears to me, we can only deal satisfactorily with the total amount of radiant heat which is active under the conditions of the experiment, the terrestrial heat being in all comparative experiments the same.

"The determination of the chemical principle of the solar rays, or actinism, permeating the media employed, required more exact attention than the other phenomena. Dr. Daubeny ascertained this by placing paper washed with nitrate of silver behind the coloured screen; and in my early experiments I was satisfied with using tolerably sensitive chloridated photographic papers for the same purpose.

"The experience of many years enables me now to state that we are not acquainted with any transparent medium which is absolutely opake to actinism. Although nitrate of silver, or indeed any of the salts of silver remain unchanged behind yellow glasses and fluids, yet chlorophyl is deoxidized and turned yellow by the chemical principle which is enabled to permeate them. Upon all those bodies on which *light* exerts a direct and determinate influence, as upon the organized compounds, we find that the changes due to *actinic* power are but slightly interfered with, whereas upon all those inorganic bodies which undergo a change when exposed to the solar chemical radiations, that change being entirely due to actinism, light acts as a powerfully interfering agent. The conditions under which these antagonistic forces—light and actinism—operate upon each other are unknown to us, but it is certain that every combination of an inorganic salt with an organic body presents a different scale of action.

"As it is, however, possible, that some source of error may exist in my experiments, I shall distinctly state every form of apparatus employed by me, and the actual conditions of the solar radiations under which the different results were obtained.

"In the first place I shall record my experiments on germination.

"It became important to determine if any effect was produced by white light. For the purpose of ascertaining this, a quantity of common cress (*Lepidium sativum*) and turnip-seed (*Brassica napus*) was placed upon moist earth, and very lightly covered with fine sand; one half was screened from the light by a blackened board, and the other freely exposed. Under the shaded half the germination was between two and three days in advance of the exposed portion.

"This experiment was repeated, using a glass trough containing a weak solution of bichromate of potash half an inch in thickness, over the illuminated portion. This solution admitted the permeation of eighty-seven parts of the luminous rays, ninety-two of the calorific rays, and twenty-seven of the chemical rays. The object in this instance was to ascertain if any greater retardation was produced by the luminous rays, from which the chemical principle was to a considerable extent removed, than by pure white light, which it will be borne in mind I propose to regard as a compound of one hundred parts of each, light, heat, and actinism. The result was, that the seeds under the influence of this yellow medium, did not germinate until five days after the seeds in the dark part of the box.

"Upon substituting a solution of sulphate of chromium and potash which admitted the permeation of eighty-five parts of light, ninety-two parts of heat, and only seven of actinism, the germination was prevented entirely in four experiments; and in the fifth, ten days after the seeds in the dark had germinated, half a dozen of seeds of cress showed symptoms of germination. These experiments were many times repeated, and always with similar results. We have thus satisfactory evidence, that light deprived of the principle or power of chemical action arrests the development of the plant, by preventing the vitality of the germ from manifesting itself.

"Although the visible sign of germination is the process of chemical combination of the carbon with oxygen and hydrogen, yet the power influencing this change is of an occult character, though evidently dependent on some external excitation, which I have proved not to be light, or the principle producing the phenomena of colour. We may now, without fear of being misunderstood, declare as a law, that in its relation to vegetable life LIGHT *prevents germination*.

"It now became important to ascertain if the chemical principle of the solar rays produced any acceleration of the germinative process. With this view, a box was prepared, in which was placed moist flannel, and this was kept wet by an under-layer of water. One half could be completely screened from the light, and the other half exposed to any influence which it was thought desirable to try.

"The luminous rays were obstructed by the interposition of a series of blue glasses, and by solutions of sulphate of copper, or ammoniate of copper.

"The tested glass admitted the permeation of—light forty, heat seventy-two, and of actinism ninety parts.

"The trough of sulphate of copper obstructed more heat, but admitted the passage of a larger quantity of light. It gave, on examination, light sixty, heat fifty-four, and actinism ninety-three parts.

"The solution of ammoniate of copper was of so deep a colour that only twenty-five parts of light passed it, and forty-eight of heat, whilst from ninety-three to ninety-five of actinism escaped any absorption.

"Common cress (*Lepidium sativum*), Mignionette (*Reseda odorata*), Ten-week Stocks (*Mathiola incana*), and Minor Convolvulus, were placed on the moist flannel, and the tested glass frame being placed over the undarkened half, the box was exposed to sunshine in a warm room. The cress under the actinic influence exhibited signs of germination within twenty-four hours, but no change was observable beyond a swelling of the seed from the absorption of water over that portion in darkness: on the second day all the cress had germinated over the exposed parts, and the other seeds were apparently in a forward condition, whereas in the dark, with the exception of the cress in which germination was established, but little alteration was seen in the other seeds. Although the period of germination differed in each variety of these seeds, under the conditions to which they were exposed, yet in every instance the seeds influenced by actinic radiations germinated in one-half the time of those seeds placed in the dark.

"The experiment was repeated, the seeds being placed in earth instead of on moist flannel. In every experiment the seeds germinated in much less time under the influence of the actinic rays than in the dark.

"Several arrangements were made for the purpose of ascertaining if the influence of the chemical rays was confined to the surface of the soil, or if they extended below it. The result was, that I obtained the most satisfactory evidence, that under the influence of the rays which passed the blue glasses, germination was set up at a depth below the surface, at which, under the ordinary conditions, it did not take place. The common cress, placed an inch below a somewhat clayey soil, germinated with difficulty under the ordinary conditions, but the influence of the actinic radiations was such, that germination was but slightly retarded. Various other seeds were tried, as,

Groundsel	*Senecio vulgaris.*
Convolvulus	*Convolvulus minor.*
Vetches	*Vicia sativa.*
Oats	*Avena sativa.*
Ten-week Stocks	*Mathiola annua.*
Mignionette	Reseda odorata.

In every instance germination was set up, by the agency of the radiations which had permeated the blue glasses, in a less time, and at a greater depth in the soil, than in comparative experiments in which the seed was exposed to the full influence of light and its associated radiations, as combined in the ordinary solar beam.

"It is evident, therefore, that this first spring of vitality is due to some power or principle of solar origin, which is very broadly distinguished from the luminous or colour-giving principle. The manner in which this power is exerted on seed beneath the soil is not clear to us; we know not if it is a mere disturbance of something already diffused through matter, or an emanation from the sun: all we are enabled to declare, is, that *the germination of seeds is more rapid under the influence of the actinic rays, separated from the luminous ones, than it is under the influence of the combined radiations or in the dark.*

"If the young plant continues to grow under the influence of the rays which have permeated the blue media employed, it will for some time exhibit a luxuriant growth, and present in its early stages an appearance far superior to that of plants grown under other modified influences, or even under white light: the leaves will be of a darker green, and altogether externally show signs of vigorous health. Even in the earliest stages of growth it will be found, however, that the plants grown in the full sunshine, or under the influences of yellow or red media, representing the luminous and calorific principles, give a larger quantity of woody fibre and less water than those grown under actinic influence. Comparative experiments were several times made for the purpose of testing this point.

"By continuing, however, the experiment for a longer time under the influences already described, we learn that the actinic radiations exert a power on the plant, which, although I have previously described it, I shall particularly call attention to in this place.

"It frequently happens, when the media employed cut off a large quantity of light and admit the actinic principle freely, that no formation of leaves takes place after the development of the plumule or first leaf-bud; the young stem instead of solidifying remains soft, and, without increasing in diameter, continues to elongate until at last it attains to an enormous length. Nothing like this occurs under the influence of either light or heat. It would appear that this abnormal condition is due to the excitement of the actinic rays, acting possibly with great power upon the living principle in the roots, by which the elaboration of some organizable matter is produced, which they supply as food to the stem; but, as there is but little power to decompose carbonic acid, there is not the necessary supply of carbon to give rise to those stems and leaves which naturally form upon the primitive stem.

"This power of decomposing carbonic acid under the influence of the solar rays is a function due to some vital principle; for I have again and again proved the correctness of *Matteucci's* statement (Supplément à la Bibliothèque Universelle de Genève), that 'toute espèce de feuille qui a été coupée et broyée ne donne plus de trace d'oxygène quand on l'expose au soleil dans de l'eau impregnée d'acide carbonique.' Further than this, I have found that more oxygen is given off from a growing plant than from a branch broken from the plant; and that still less is given off from the leaves cut from the branch than when they are attached to it.

"I have, from numerous experiments which I have made, every reason to believe, that it will be found that there is as great a difference between the effects produced on growing plants by the prismatic rays, as we know to be the case on photographic preparations; the maximum effect altering, perhaps, for every variety of plant.

"The conclusions I am induced to draw from these experiments are, that the luminous principle of the sun's rays is essential to enable the plants to effect the decomposition of the carbonic acid of the atmosphere, and form the woody structure; that some plants require more light than others to effect this decomposition; as, for instance, we find the sage and ten-week stocks decomposing carbonic acid with less light than the cabbage or mint; and it would appear that the increase of the luminous excitement beyond a certain point does not produce a corresponding increase in the quantity of gas liberated from the leaves of these plants.

"I have rarely succeeded in getting plants to flower under the influence of any of the media which cut off those rays usually termed the calorific rays. For instance, under intense yellow, deep blue, or very dark green glasses, however carefully the plants may have been attended to, there was seldom any evidence of the exertion of their reproductive functions. This evidently arises from the necessity of some check upon the chemical actions which depend on light and actinism, and which exhaust the elements in the formation of wood and the vegetable juices necessary for the production of those principles which go to the preservation of the species. By removing plants when in a healthy condition from the influences of isolated light or actinism to a situation where they may be exposed to the effects of those heat radiations which are of the least refrangible class, flowers and seed are rapidly produced.

"This is not an effect of heat (*quoad* heat), since the same temperature may be maintained under all the circumstances, yet if the red rays are obstructed, flowers will not form. It is therefore evident, that this very remarkable property must depend upon some function peculiar to this class of rays. The researches of Sir John Herschel, Dr. Draper, M. Claudet, and myself, on the action of the rays of the spectrum on photographic preparations, most materially assist us in explaining this phenomenon.

"The results to which my experiments have led me, are—

"1st. Light prevents the germination of seeds.

"2nd. Actinism quickens germination.

"3rd. Light acts to effect the decomposition of carbonic acid by the growing plant.

"4th. Actinism and light are essential to the formation of the colouring matter of leaves.

"5th. Light and actinism, independent of the calorific rays, prevent the development of the reproductive organs of plants.

"6th. The heat radiations, corresponding with the extreme red rays of the spectrum, facilitate the flowering of plants and the perfecting of their reproductive principles.

"In the spring I find the actinic principle the most active, and, as compared with light and heat, in considerable excess.

"As the summer advances, the quantity of light and heat increases relatively to the actinic principle, in a very great degree.

"In the autumn, light and actinism both diminish, and the calorific radiations are, relatively to them, by far the most extensive.

"It should be again explained, that by *light* I mean to express all those rays of the spectrum which are visible to a perfectly-formed human eye; by *actinic principle*, the principle to which the phenomenon of chemical change under solar influence belongs; and by *calorific radiations*, not merely those effects which are traceable by any thermometric instruments, but also those which we can detect by the protection from change, produced by a class of rays existing near the point of maximum heat in the spectrum.

"These discoveries teach some important truths; and, at the same time as they appear to confirm in a most satisfactory manner the conclusions to which my results have led me, they point to an order in the natural arrangement which is singularly interesting.

"In the spring, when seeds germinate and young vegetation awakes from the repose of winter, we find an excess of that principle which imparts the required stimulus; in the summer, this exciting agent is counterbalanced by another possessing different powers, upon the exercise of which the structural formation of the plant depends; and in the autumnal season these are checked by a mysterious agency, which we can scarcely recognize as heat, although connected with thermic manifestations, upon which appear to depend the development of the flower and the perfection of the seed."

It has now been shown that all matter is under the influence of certain fixed laws which regulate its molecular arrangement, and we regard these as mechanical forces;—that the operations of these are modified by the influences of heat, electricity, and probably of light. Chemical forces come most actively into play in determining the conditions of ponderable matter; but beyond those chemical phenomena which are due to the operation of a radiant power—actinism,—it has not been thought advisable to involve the present treatise with any consideration of the laws of affinity.

We shall see, upon consideration of the subject, that the present condition of the earth on which we live, is due to the antagonistic operations of the physical forces we have been studying, andthat from the harmonious action of these, springs that order and beauty which is spread around us. In the smallest dust floating on the summer breeze all these physical forces are as much in action as they are in the great globe itself, or in the living organisms which are placed upon its surface. Let it not, however, be forgotten, that although the physical powers which we have been studying are necessary to vitality, they do not produce Life,—vital force is a power superior to every physical influence, holding them in strong subjection, and it is only when death ensues that they are left to act in all their power on organic matter.

It is important, too, to remember that every motion which can take place in the material universe is due to the operation of a physical force; that to physical powers belong that motion which is demanded in the eternal progress of nature; and to argue that motion may resolve itself into the varied forms of force with which we are acquainted, amounts only to an admission of our ignorance of those vast powers which are created as the great controllers of the universe.

TABLE OF SPECIFIC GRAVITIES.

Extracted from Davies, Lavoisier, Young, and other authentic sources.

Note.—Water at 60° is assumed 1000 specific gravity.

MINERAL PRODUCTIONS.

Platinum, purified	19500
——— hammered	20336
Pure gold, cast	19258
——— hammered	19361
Mercury	13568
Lead, cast	11352
Silver, pure, cast	10474
——— hammered	10510
Bismuth, cast	9822
Copper, cast	8788
——— wire	8878
Brass, cast	8395
—— wire	8544
Cobalt, cast	7812
Nickel, cast	7807
Iron, cast	7207
—— bar	7788
Steel, hard, not screwed	7816
—— soft, not screwed	7833
Loadstone	4800
Tin, cast	7291
Zinc, cast	7190
Antimony, cast	6702
Tungsten	6066
Arsenic, cast	5763
Molybdenum	4738
Spar, ponderous	4430
Ruby, oriental	4283
Garnet, Bohemian	4188
Sapphire of Puy	4076
Topaz, oriental	4010
Beryl, or oriental aquamarine	3548
Diamond, rose-coloured	3531
——— white	3521
——— lightest	3501
Glass, flint	3329
—— white	2892
—— bottle	2732
—— green	2642
Fluor	3191
Serpentine, green	2988
Mica, black	2900
Basaltes, from the Giants' Causeway	2864
Marble, white, Parian	2837
——— green	2741
——— red	2725
——— white, of Carrara	2716
Emerald, Peruvian	2771

Porphyry, red	2765
Jasper	2764
Alabaster, white, antique	2730
Calcareous spar, rhombic	2715
——— pyramidal	2714
Slate	2671
Pitch-stone	2669
Onyx, pebble	2664
Chalcedony, transparent	2664
Granite, Egyptian, red	2654
Rock crystal, pure	2653
Amorphous quartz	2647
Agate, onyx	2637
Carnelian	2613
Sardonyx	2602
Purbeck stone	2601
Flint, white	2594
—— blackish	2581
Agate, oriental	2590
Prase	2580
Portland stone	2570
Mill-stone	2483
Paving-stone	2415
Touchstone	2415
Porcelain, Chinese	2384
Lapis obsidianus	2348
Selenite	2322
Grindstone	2142
Salt	2130
Sulphur, native	2033
Nitre	2000
Brick	2000
Plumbago	1860
Alum	1720
Asphaltum	1400
Coal, Scotch	1300
—— Newcastle	1270
—— Staffordshire	1240
Jet	1238
Ice, *probably*	930
Pumice-stone	914

LIQUIDS.

Sulphuric acid	1840
——— Ph. London	1850
Nitrous acid, Ph. London	1550
Nitric acid	1217
Water of the Dead Sea	1240
Sea water	1026
Muriatic acid	1194
Water of the Seine, filtered	1001
Naphtha	708

ELASTIC FLUIDS.

	Kirwan. Barometer 30.	*Lavoisier.* Thermometer 52°.
Sulphurous acid gas	2·265	——
Carbonic acid gas	1·500	·00176
Nitrous gas	1·194	——
Sulphuretted Hydrogen	1·106	——

	Kirwan. Barometer 30.	*Lavoisier.* Thermometer 52°.
Oxygen gas	1·103	·00137
Atmospheric air	1·000	·00128
Nitrogen gas	·985	·00120
Ammoniacal gas	·600	——
Hydrogen gas	·084	·000096

VEGETABLE PRODUCTIONS.

Sugar, white	1606	Vinegar, distilled	1009
Gum Arabic	1452	Water at 60°	1000
Honey	1450	Bordeaux wine	994
Catechu	1398	Burgundy wine	991
Pitch	1150	Turpentine, liquid	991
Copal, opake	1140	Camphor	988
Yellow amber	1078	Linseed oil	940
Malmsey, Madeira	1038	Elastic gum	933
Cider	1018		

ANIMAL SUBSTANCES.

Pearl	2750	Wax, white	·96
Coral	2680	—— yellow	965
Sheep's bone, recent	2222	Spermaceti	943
Oyster-shell	2092	Butter	942
Ivory	1917	Tallow	942
Stag's horn	1875	Fat of hogs	937
Ox's horn	1840	—— veal	934
Isinglass	1111	—— mutton	923
Egg of a hen	1090	—— beef	923
Human blood	1053	Ambergris	926
Milk, cow's	1032	Lamp-oil	923

WOODS.

Pomegranate-tree	1354	Heart of oak, 60 years felled	1170
Lignum vitæ	1333	Oak, English, just felled	1113
Box, Dutch	1328	—— the same, seasoned	743
Ebony	1177		

Oak, Engl., usually stated at	925
Bog oak, of Ireland	1046
Teak, of the East Indies	745–657
Mahogany	1063–637
Pear-tree trunk	646
Medlar-tree	944
Olive-wood	927
Logwood	931
Beech	852
Ash	845–600
Yew, Spanish	807
—— Dutch	788
Alder	800
Elm	800–600
Apple-tree	793
Plum-tree	755
Maple	755
Cherry-tree	715
Quince-tree	705
Orange-tree	705

Walnut . . . .
Pitch pine . . . . . .
Red pine . . . . . .
Yellow pine . . . . .
White pine . . . . .
Fir, of New England .
— of Riga . . . . .
— of Mar Forest, Scotland . . . . . .
Cypress . . . .
Lime-tree . . . . . .
Filbert wood . . . . .
Willow . . . .
Cedar . . . .
Juniper . . . .
Poplar, white Spanish .
——— common . . .
Sassafras wood . . .
Larch, of Scotland . .
Cork . . . .

INDEX.

Page.
Aberration of light . . . 392
Absorption of light . . . 369
Accidental properties of matter . . . 8
Acoustics . . . 176
Actinism and light . . . 379
—— *Ray power* . . . 430
Adams on the planet Neptune . . . 51
Adhesion of snails, &c. . . . 141
Aerial currents . . . 155
Adhesive force of flowing water . . . 125
Adiathermasy and Diathermasy . . . 373
Agents, photographic . . . 436
Aggregative attraction . . . 15
Air, a fluid . . . 137
—— impenetrability of . . . 138
—— phenomena of waves of . . . 184
—— resistance of, to falling masses . . . 58
Air-pump . . . 142
Amorphous bodies . . . 33
Ampère's theory of magnetism . . . 312
Anatomy of the eye . . . 38

Page.

Animal electricity: animals possessing power of generating electricity 265-267
———— phenomena of 264
Aneroid barometer 152
Aqueducts, Roman 108
Aqueous vapour in the atmosphere 156
Arago on electro-magnetic induction 317
Archimedean screw 130
Archimedes, the laws of specific gravity developed by . . 68
Artesian wells 109
Assimilation in animals effected by endosmose . . . 30
Atmosphere, condition of 135
—— a magnetic medium 327
—— absorption of heat by 155
—— electricity of 233
Atmospheric refraction 398
Atom, ultimate 3
Attraction, cohesive 15
—— at insensible distances 1
Attwood's machine for falling bodies 57
Aurora Borealis, description of 328
Avoirdupois weight 65

Bailey's (Francis) experiment on gravitation 45
Balances 64
Balls, whirling 12
Barker's mill 127
Barometer, the 148
—— fluctuations of the 151
Beam, the 63
Becquerel's battery 252
Bellows, hydrostatic 117
Bernoulli on flowing water 123
Biot on the limits of the atmosphere 137
Bodies, falling, deviation of 53

Page.
Bodies, moving, influenced by gravitation 56
—— reduced to a solid state by Thilorier's bath 360
Boiling point of water 354
Bologna, leaning tower of 72
Boutigny's experiments on heat 377
Boyle on the divisibility of matter 2
—— on the elasticity of the air 139
Bramah press 116
Brunel on the fracture of iron 33
Brougham's (Lord) investigations of light 381
Bunsen's voltaic battery 250
Buoyant force of water 120

Caloric, or heat 331
—— or principle of heat 337
—— conduction of, through solids 345
—— radiant condition of 365
—— absorption of 369
Calorific phenomena of electricity 258
—— power 437
Calotype process 434
Canton on compressibility of water 106
Camera obscura, construction of 383
Capillary attraction 20
Carbon, different conditions of 34
Catalysis 19
Catoptrics 393
Caoutchouc, elasticity of 39
Cavendish, experiment on gravitation 45
Cells, vegetable 38
Centre of gravity 71
—— of inertia 74
Centrifugal force 97
Centripetal force 97
Cerulin, extreme divisibility of 3

Page.
Charcoal, its power of condensing gases 18
Chatsworth, great fountain at 109
Chemical action suspended at high temperatures . . . 377
—— power of the solar rays 438
Chemistry, great but not infinite divisibility proved by . . 3
Children's voltaic battery 249
Chinese bead-pumps 133
Chromatic aberration of light 415
Chthonisothermal line 363
Choke-damp 173
Cirrus cloud 165
Circle, the 48
Clocks regulated by pendulums 61
Clouds 164
Clement-Desormes on the flow of compressed air . . . 174
Clepsydra 123
Coal-mine ventilation 171
Cohesion 1, 15
Colour, not a test of difference of refrangibility . . . 409
Coloured light, phenomena of 405
Colours, phenomena of 421
Composition of motion 82
Compressibility of water 106
Compression of air 139
Condamine on the attraction of mountains 52
Conducting power, Rumford on 346
Conic sections 48
Construction of thermometer 341
—— of pendulums 340
Coulomb's torsion balance 210
Crystals, increase of, not growth 37
Crystallization, earthy and metallic 36
—— of substances of dia-magnetic character . . . 300
Crystalline structure 33
Cumulus cloud 165

Page.
Currents, and effects of various coloured glass screens . . 437
Cycloid, the 83
Cyclone, the 99

Daniell's hygrometer 162
—— pyrometer 343
—— voltaic battery 250
Daguerre, process of 433
Definite proportions a proof against infinite divisibility . . 3
Density of the atmosphere 135
—— of matter 7
Despretz on conducting power 344
Dew, cause of 371
Dew-point, the 162
Dia-magnetism, explanation of 297
Dia-magnetic metals, list of most remarkable . . . 298
Diameter, equatorial and polar, of the earth . . . 13
Diathermasy and adiathermasy 25
Diffusion of gases 374
Dioptrics 393
Dispersion of light 414
Displacement of liquids by solids 118
Distilling apparatus, explanation of 352
Divisibility of matter 26
Dove on the winds 159
Ductility of metals 38
Duhamel's method of magnetizing steel bars . . . 289
Dulong and Petit on expansion 343
Dutrochet on endosmose 28
Dynamics 9

Ear, the 176
—— passages and organs of the 177
Earth, the revolution of the 11
Echoes, remarkable instances of 191

Page.
Efflux of water 123
Elasticity of bodies 38
Ellipse, the 48
Endosmose 28
Elastic fluids, laws of 134
———— laws of slightly 105
Elasticity of water 106
Elasticity of steam 355
Electric batteries, luminous effects of 260
physiological effects of 261
—— current, magnetic character of 303
—— light 230
———— rapidity of 260
———— development of 220
—— machines, description of 213
—— telegraphs, description of 309
—— conductors, description of 212
—— discharge, force of 228
—— repulsion, example of 227
Electrical eel 266
Electricity, animal, phenomena of 264
atmospheric 233
peculiarities of 235
Franklin's kite 234
origin of 236
—— calorific phenomena of 258
—— power of bodies to conduct 255
—— excitation of 257
—— intensity of: the law of Ohm 256
—— mode of ascertaining the quantity of electric power of different bodies 205
—— striking peculiarities of 217
—— luminous effects of 260
—— peculiar phenomena of 199
—— primary phenomena of 199

Page.
Electricity, theoretical explanation of 216
—— vital, experiments on 263
Electrics, character of 211
—— negative and positive 270, 271
Electro-dynamics: action of currents 311
Electro-magnetic induction, Arago's discovery of 317
Electro-magnetism, experiments with 284–288
Electro-magnets, construction of 305
———— experiments with 299
———— economic difference between a steam-engine and an electro-magnetic engine 308
———— power of 306
———— reciprocating action of piston-like temporary magnets 307
Electrometer, form of 209
—— Coulomb's 'torsion balance' 210
—— Sir W. S. Harris's hydrostatic 211
Electromotive force 245
Electromotors: list of metals which will produce electromotive force 245
Electroscopes, description of 207
Electro-metallurgy, process of 272
Electrophorus 217
Electrotype apparatus, description of 273–282
Elliptical polarization of light 429
Engines, hydraulic 126
Epipolic force 20
Equilibrium, statical 84
Escapement, watch or clock 62
Exosmose 28
Experiments on the chemical power of rays 431
Extension of matter 6
Eye, formation of the 381

Faraday on electro-dynamic induction 318

Page.

Faraday, his theory of electricity 203

—— his electrical apparatus 326

Fata Morgana 398

Fay and Symmer's theory of electricity 201

Feather and guinea experiment 59

Ferrotype process 434

Fire-damp 172

Floating bodies, laws of 119

Florentine academicians on the compressibility of water . 106

Flow of water through orifices 121

Fluids at rest 105

—— specific gravity of 70

—— uniform height of 107

Force of winds 159

Forces, attractive 38

—— parallelogram of 83

Forcing-pump 132

Fountains 109

Fox's wedge for blasting rocks 88

Franklin's experiments on solar radiations of caloric . . 372

—— kite experiment 234

Franklinian theory of electricity 202

Fraunhofer's dark lines 414

—— investigation of the phenomena of light . . . 421

Freezing mixtures 356

—— points of fluids 359

French decimal system of weights and measures . . . 66

Friction 79–94

Fusion or melting of metals, &c. 349

Galvanic influence of rays of light 437

Galvanism 242

Galvanometer, Nobili's description of 304

Gases, diffusion of 25

Gaseous bodies, permanent 166

Geyser, the, in Iceland 110

Page.
Germination, experiments on 442
Graham on the diffusion of gases 25
Grove's voltaic battery 250
Glass, cohesion of plates of 16
Gold, most ductile of bodies 39
—— extreme divisibility of 2
Gravitation 7, 43
Goethe's theory of colours 413
Gutta percha, electrical properties of 200
Guyton-Morveau on attractive force 16
Gymnotus 266

Hales on the sap in trees 76
Haloes 398
Hare's voltaic battery 249
Harmonicon, chemical, description of the 196
Harris's hydrostatic electrometer 211
Harris on electro-magnetic induction 318
Heliographic process 435
Heat, or caloric 331
—— principle of 337
—— cause of dew 370
—— chemical action a source of 335
—— conducting power of various bodies 344
—— construction of air thermometer 338
—— mechanical force of 334
—— obeys many laws which regulate the motion of light . 375
—— power of various bodies to reflect 368
—— radiant, science of, or thermotics 366
—— radiant, propagation of 367
—— rates of expansion of solid bodies by 339
—— specific 347
—— subterranean 364
—— theory of exchanges of 370
—— vital action of 336

Page.
Height determined by barometer 148
—— of the atmosphere 136
Heights of snow lines 363
Hemispheres, Magdeburg 145
Hero's sphere 145
Herschel's method of examining the temperature of solar rays 333
—— telescope 403
Hoops, revolving 12
Horizontality of fluids 112
Howard, Luke, on clouds 165
Horse-shoe magnets 289
Humboldt's lines of equal annual temperature 362
Huyghens's law of double refraction of light 424
Hydraulics 120
Hydraulic engines 126
Hydro-electric machine, description of 218
Hydro-electricity, elementary phenomena of 246
Hydrostatics 105
Hydrostatic bellows 117
—— paradox 113
—— press 116
Hygrometers 162, 163
Hyperbola, the 48

Illuminating power of the planets 390
—— of the prismatic spectrum . . . 412
Imperial system of weights and measures 66
Inclined plane 85
India-rubber, elasticity of 39
Inertia 7, 62, 74
—— centre of 74
Interference of waves 183
—— of light 424
Iron, changes of the molecules of 33
—— sulphate of, crystallization of the 300

Page.

Jets of liquids, law of the flowing of 122
Jupiter, mass of the planet 49

Kaleidophon, Wheatstone's 181
Kite, electrical 234
Knight's magnets 291

Lacerta gecko of Java 141
Laplace on the earth's motion 80
—— on the stability of the ocean 76
—— on the motion of the planets 49
Laws of magnetic arrangement 295
Law of storms 98
Length and weight, relation of 66
Lenses 399
Levelling, art of 112
Lever, the 91
Le Verrier on the planet Neptune 51
Leyden jar, description of 221
Light, aberration of 392
—— and actinism 379
—— coloured 405
—— degree of illuminating power 390
—— carbonic acid decomposed by 450
—— dioptrical phenomena of 395
—— Fraunhofer's investigation and description of phenomena of 421
—— may be decomposed by absorption 408
—— physiological effects of 381
—— polarization of 425
—— power of, in inducing magnetism in steel 329
—— movement of 391
—— photometers 390
—— propagation of 389
—— production of 38

	Page.
Light, progression of, undulatory	380
—— velocity of artificial	392
Lightning, description of	237
—— conductors, description of	240
Liquefaction of bodies	355
—— of metallic alloys	350
Liquids, diffusion of	27
—— pressure of	114
Luminous intensity of the rays of light	412
—— power	437
———— of electricity	260
Lunar influence on tides	55
Lycopodium, physical property of	24
Machines, electric	213
Machine for freezing	357
Magdeburg hemispheres	145
Magnetic action of voltaic current	305
—— arrangement, laws of	292
—— character of electric current	303
—— character of the various metals	295
—— electricity	283
—— induction, Dr. Scoresby's phenomena of . . .	291
—— medium of the atmosphere	327
—— needle, affected by the sun's course	323
———— affected by electric discharges	302
———— the dip or inclination of	321
Magnetism, Ampère's theory of	312
—— assumed to be a peculiar form of electricity . .	327
—— of the earth, phenomena of the	324
—— proof of the universality of	301
—— terrestrial, phenomena of	318
Magnets, Dr. Knight's artificial	290
—— horse-shoe	289
—— lifting or sustaining power of	291

Page.
Man, adjustment of centre of gravity by 73
Mariotte, law of 139
Maskelyne's experiments on attraction 52
Mass, influence of, on gravitation 46
Matter, is it infinitely divisible? 2
—— inert 62
—— ultimate point of 9
—— solid, plastic, fluid, liquid, vaporiform, gaseous . . 5
Mechanical power 85
Melloni's thermo-electric pile 376
Mercury, extreme divisibility of 3
Metallic mirror 366
Metals, magnetic character of various 296
dia-magnetic 298
Microscopes 403
Mirage 398
Mirrors, concave and convex 394
description of 393
Molecular forces 18
Molecules, movement of 32
Monsoons 157
Moon, influence of, on tides 55
Moseley on tenacity 38
Motion, composition of 82
—— general laws of 79
—— modes of producing force 101
—— of gases 168
—— primary, considered 103
—— rectilinear 82
—— relative or absolute 81
—— resolution of 83
—— results of 11
Musical notes, production of 192

Neap *tides* . . . . [illegible]

	Page.
Needle, variation of	319
Neptune, discovery of the planet	51
Newton's (Sir Isaac) law of gravitation	45
———— laws of motion	79
———— telescope	403
———— theory of matter	10
———— theory of light	416
Nimbus, or rain-cloud	165
Northern lights, electrical manifestations of	323
Nobili's galvanometer, description of	304
Œrsted on the deviation of falling bodies	53
—— on the elasticity of air	139
Ohm's law of the intensity of an electric current	256
Oil, revolving globe of	14
Optics	393
Organ-pipe, to imitate human voice	198
Organic form	36
—— arrangement	37
Orifices, liquids flowing from	121
Oscillations of the pendulum	60
Otto von Guericke, the air-pump invented by	142
Parabola, the	48
Parabolic curve formed by projectiles	56
Parallelogram of forces	83
Particles of solids, movements of	31
Pendulum, the	59
Pendulums, construction of	340
Perkins, experiments by	106
—— on the condensation of air	139
Phenomena of atmospheric refraction	398
—— of interference of rays	422
—— of vision	384
Photography, light-drawing	432

Page.
Photometers, construction of 391
Physics, definition of the term 4
Physical forces, modes of motion 101
Pisa, leaning tower of 72
Plane, inclined 85
Planets, illuminating power of 390
—— relative sizes of 49
Plants, carbonic acid decomposed by 450
Plateau, M., experiment by 14
Platinum foil and sponge, condensing power of 19
Pneumatics 134
Polarization of light 439
Ponderable matter, general properties of 1
Power and time, relation of 90
Press, hydrostatic 116
Pressure of the atmosphere 140
—— of fluids 114
—— equal, of water 119
—— of water 118
———— engines worked by 129
Prévost's theory of exchanges 370
Primary and secondary colours of light 407
Principia of Newton 83
Prismatic spectrum 410
Production of colours 419
Properties of matter 6
Pulley, the 89
Pump, suction 131
—— forcing 132
Puy de Dôme, experiment upon 148
Pyrometers, construction of 343
—— Wedgewood's, construction of 343

Radiating power of various bodies 367
Rain-gauges 16

	Page.
Ramsden's balances	64
Raymond's, M. du Bois, experiments on vital electricity	263
Rectilinear motion	82
Reflection of heat	368
Refraction	395
—— Huyghens's law of	424
—— table of the indices of	397
Reinsch's voltaic battery	252
Repulsion, electrical	227
Resolution of motion	83
Rocks, structure of	35
Rotatory motion	82
Rumford's experiments on conducting power of bodies used for articles of dress and coverings of animals	346
Rutherford's self-registering thermometers	341
Saturn's ring imitated in an experiment by Plateau	15
Saussure's hair hygrometer	162, 361
Scoresby's magnets	291
Screw, the	86
Seasons, influence of, on plants	451
Seeds, germination of	446
Segner's machine	128
Silence produced by two sonorous undulations	192
Siphon, anatomical	117
Siphon, the	133
Smee's voltaic battery	249
Snow-line, the	154
——— heights of the	363
Solar influence on tides	54
—— rays, temperature of	332
—— spectrum, constitution of the	410
—— system, gravitation of the	47
Solidification of gases	167
Solids, soluble, diffusion of	27

Page.
Solids, specific gravity of . . . 70
Sonorous movements of bodies . . . 176
Sound, intensity of . . . 190
—— production of . . . 176
—— travelling of . . . 189
—— wave-motion of . . . 178
—— vibration of . . . 179
Sound-vibrations, experimental illustrations of . . . 186
Speech, organs of . . . 197
Specific gravity . . . 67
table of . . . 453
—— heat . . . 347
Spheroidal state of bodies . . . 377
Spider's web, elasticity of . . . 39
Spirit-level, the . . . 112
Spring tides . . . 54
Springs, intermittent . . . 111
Stability of bodies . . . 71
—— of the ocean . . . 76
Statics . . . 8
Steam jet . . . 173
—— electricity of . . . 219
—— as a motive power . . . 353
—— elasticity of . . . 355
St. Elmo, description of the Fire of . . . 238
Steelyards . . . 64
Stereoscope, Professor Wheatstone's . . . 385
Storms of the tropics . . . 98
Stratus cloud . . . 165
Storms, law of . . . 98
Strength of materials . . . 40
—— relative and absolute . . . 41
Strock, the, in Iceland . . . 111
Suction pump . . . 131
Sucker, the leathern . . . 141

	Page.
Sulphate of iron, formation of crystals of	300
Sulphur, amorphous and crystalline	34
Table, whirling	10
Telegraphs, electric, description of	309
Telescopes, terrestrial and reflecting	402
Temperature of the ocean	351
Tenacity of metals	38
Terrestrial or natural magnetism, phenomena of	318
Thermochroology and Thermography	374
Thermometer, air, construction of	339
——— dry and wet bulb	164
——— Rutherford's self-registering	341
——— construction of	341
Thermotics, or the science of radiant heat	366
Thilorier's bath	359
Thunder-clouds	239
Tides, phenomena of	53
Torpedo, the	265
Torricelli on the atmosphere	147
Trade winds	157
Tredgold on crushing force	39
Trees, ascent of fluids in	76
Triangle, the	48
Trochoid, the	83
Troy weight	65
Turbine, the	129
Twilight produced by the atmosphere	136
Typhoon, the	99
Undulation of water	125
Uranus, perturbations of	51
Vapour in the atmosphere	157
Variation of the needle	319

Page.
Variations of atmospheric pressure 153
Vegetation and crystallization distinguished . . . 37
Velocity of falling bodies 57
—— of light 392
—— of sound 190
—— of winds 159
Ventilation 169
Vena contracta of flowing fluids 122
Vidi's aneroid barometer 152
Vision, physiology of 382
—— single and double 386
Vital force 452
—— electricity, M. du Bois Raymond's experiments on . 263
Volta's electrophorus 217
Voltaic batteries, description of 249
—— battery, chemical effects of 268
———— Becquerel's, 252; Bunsen's, 251; Children's, 249; Cruickshank's, 249; Daniell's, 250; Grove's, 250; Grove's gas, 253; Hare's, 249; Œrsted's, 249; Reinsch's, 252; Reinsch's charcoal, 254; Smee's, 249; Wöhler's, 252; Wollaston's, 249.
Voltaic current, further proof of magnetic action . . 305
—— electricity, or galvanism 242
—— phenomena, production of 247
—— pile, construction of 248

Water, electricity of 219
—— quantity of, on the surface of the earth . . . 105
—— supply of towns with 108
—— upward pressure of 119
Water-clock 123
Water-snail 130
Waterspouts 160
Water-wheels, overshot, undershot 127
Waves of water 125

Page.

Waves, interference of 183

—— phenomena of 183

—— reflection of 182

Wedge, the 88

Wedgewood's pyrometer 343

Weight, how determined 63

—— of the air 137

—— of matter in the sun 51

Wheatstone's, Professor, stereoscope 385

—— kaleidophon 181

Wheel and axle, the 93

—— barometer 150

Whirlwinds 160

Whitelaw's engine 128

Windlass, the 94

Winds, the 155

Young, Dr., on capillary attraction 22

Printed by Reeve and Nichols, 5, Heathcock Court, Strand.

THE NEW YORK PUBLIC LIBRARY
REFERENCE DEPARTMENT

This book is under no circumstances to be taken from the Building

form 410		